

Nine In Situ Permeable Reactive Barriers Treat a Large Chlorinated Solvent Plume Beneath a City

In-situ Sorption and Enhanced Chemical Reduction

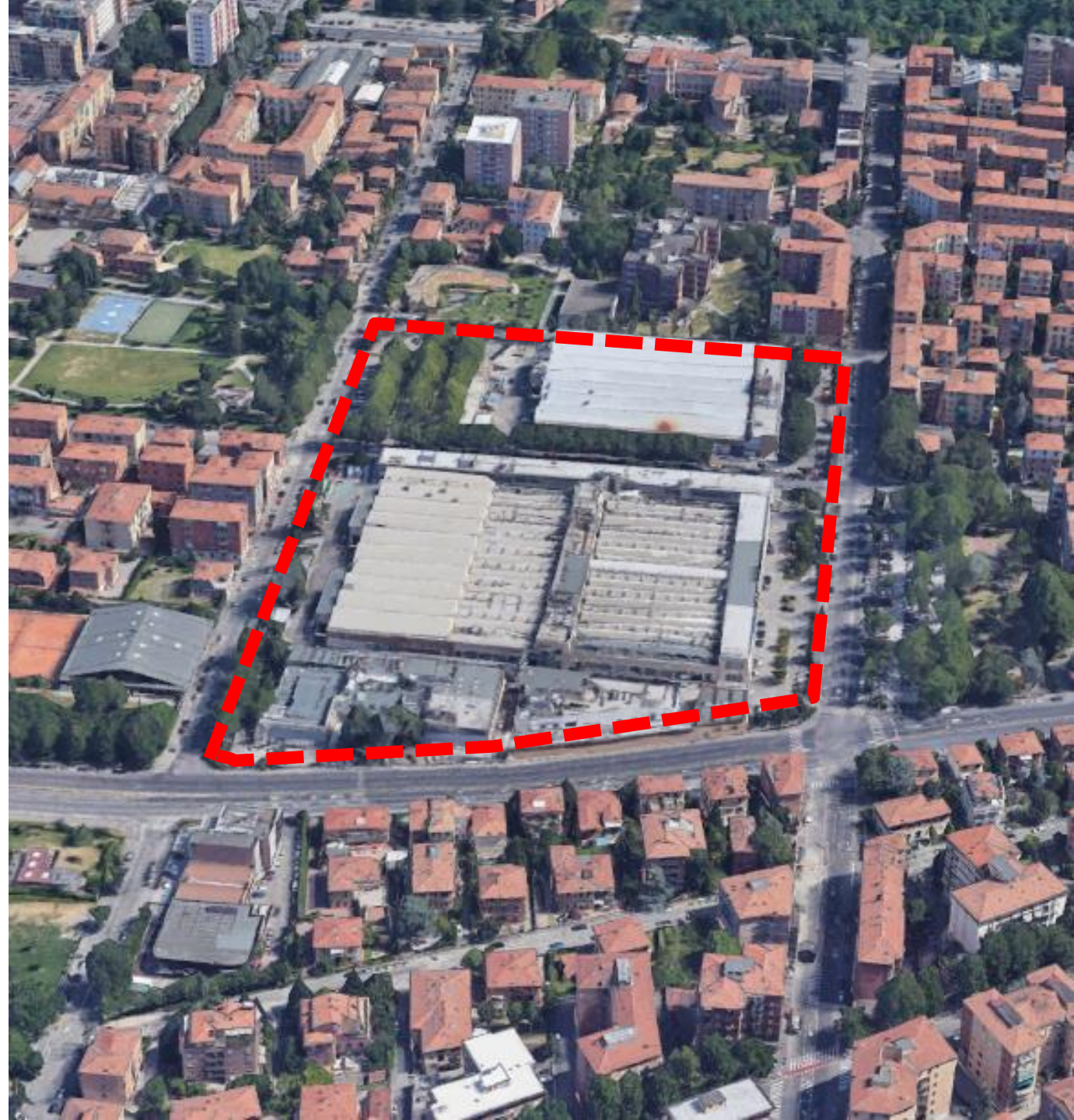


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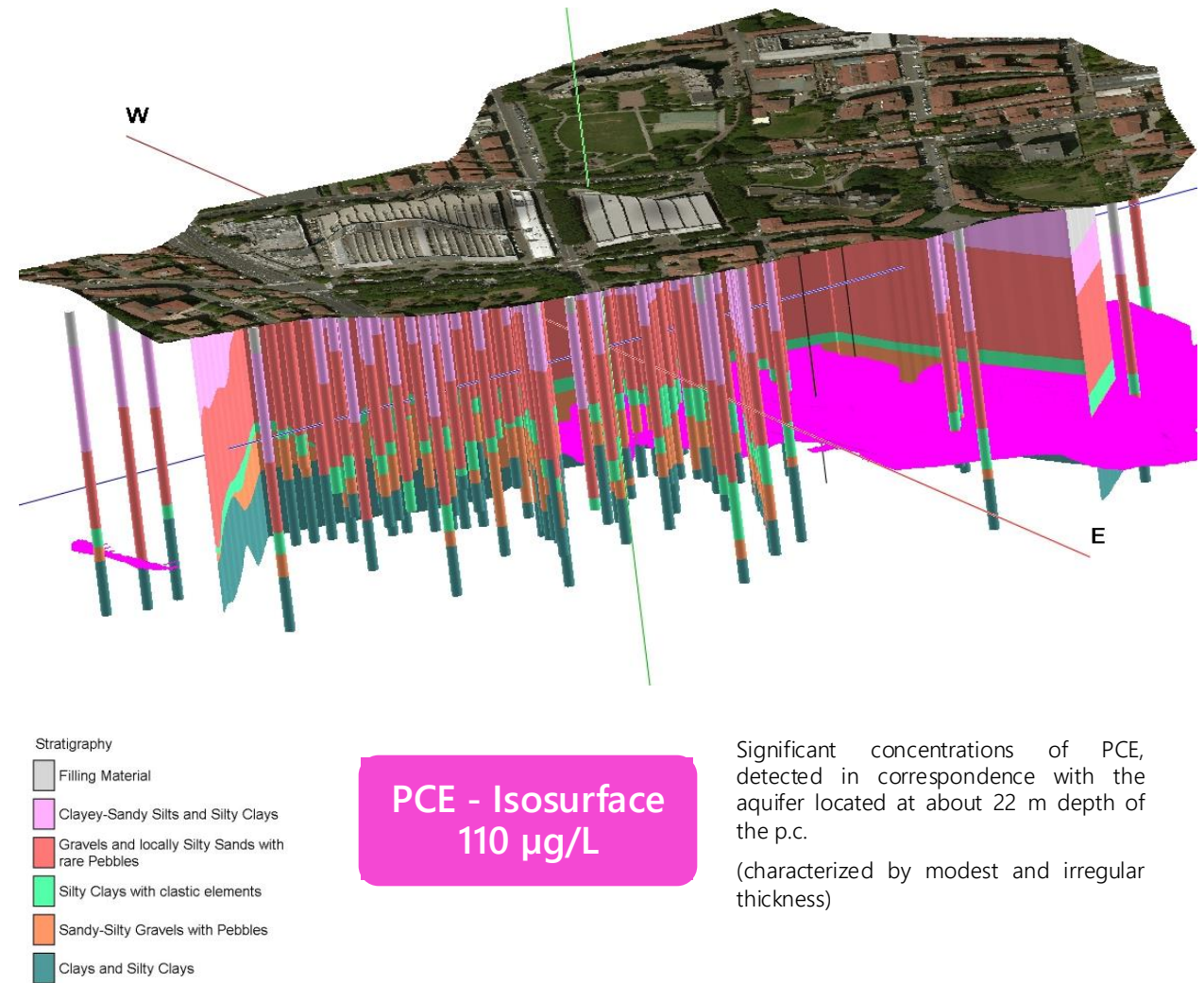
Project overview

- Historical PCE release feeding a plume beneath a densely populated area.
- The manufacturing plant is the source of a widespread PCE plume
- Hydraulic containment at the downgradient boundary since 2010 (37 wells)
- 450,000 m³ groundwater abstracted, removing about 4 tonnes of dissolved PCE
- SVE/MPE vapour extraction across four systems since 2017
- Plume still extends off-site beneath homes, schools and kindergardens
- TAUW Italia with Sapienza University of Rome and REGENESIS were tasked with implanting an in-situ remediation strategy



Site hydrogeology

- Contamination sits in a thin gravel horizon at about 22–25 m, sealed beneath cemented clays and silts.
- Made ground over clays and silts to about 10 m
- Sands and gravels 10–20 m, then clays and silty clays
- Target aquifer: gravels and sands from about 22–23 m to 24–30 m
- Treatment interval is thin, locally around 1 m, and varies over short distances
- Conceptual model built from 181 georeferenced points, 127 boreholes and 20 MIP profiles

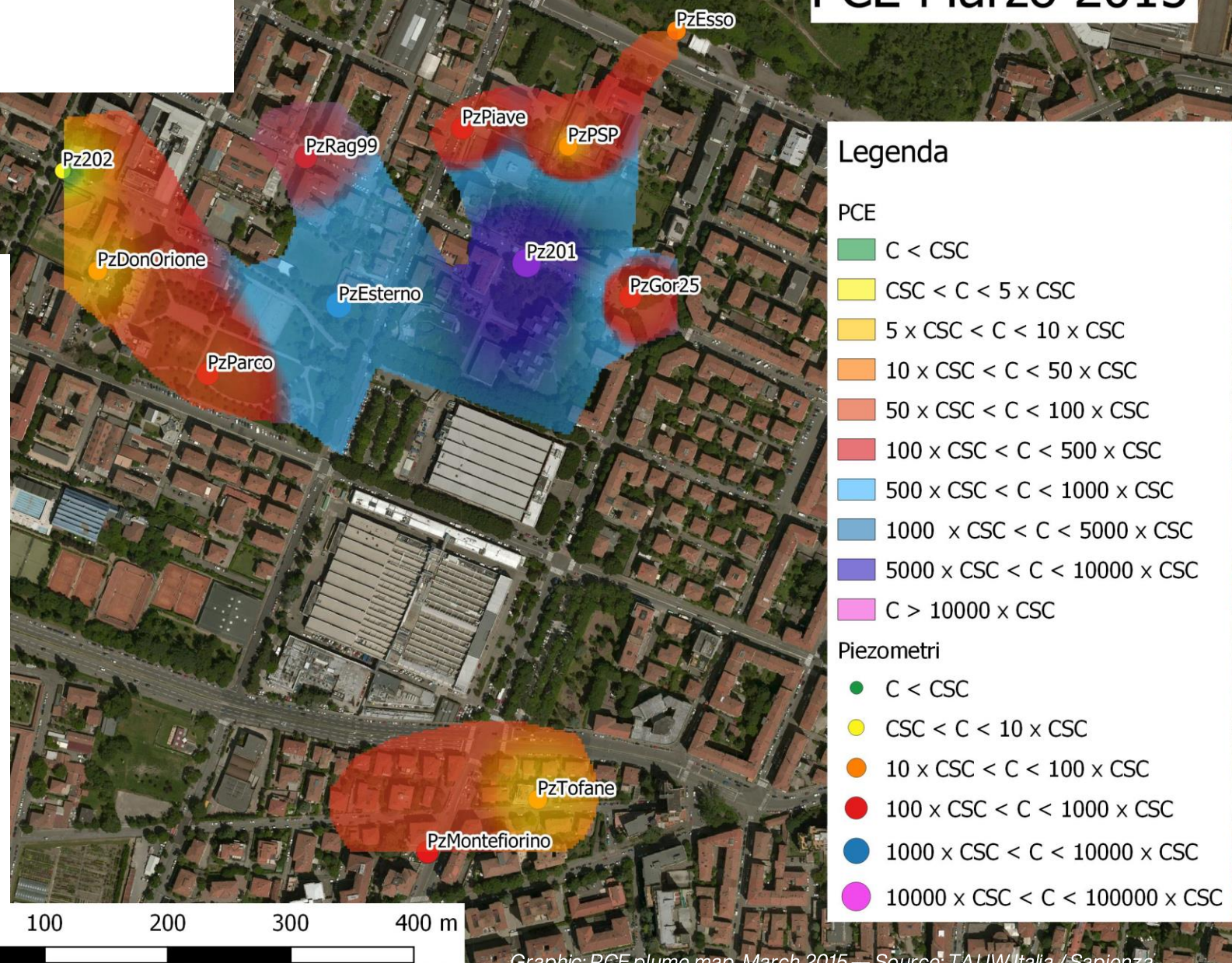


Graphic: 3D stratigraphic model — Source: TAUW Italia / Sapienza Università di Roma, REGENESIS webinar (Petrangeli, 2021).

Regulatory and remediation framework

- Concentration bands set the strategy: monitoring, injection, or physical treatment.
- Statutory groundwater standard (CSC) for PCE is $1.1 \mu\text{g/L}$
- Wider background chlorinated solvent contamination across the city
- Site-specific framework agreed with local authorities and Sapienza University
- Below $100 \times \text{CSC}$ (approx. $100 \mu\text{g/L}$): monitored natural attenuation
- $100\text{--}1,000 \times \text{CSC}$: biotic and abiotic in situ treatment
- Above $1,000 \times \text{CSC}$: physical interventions

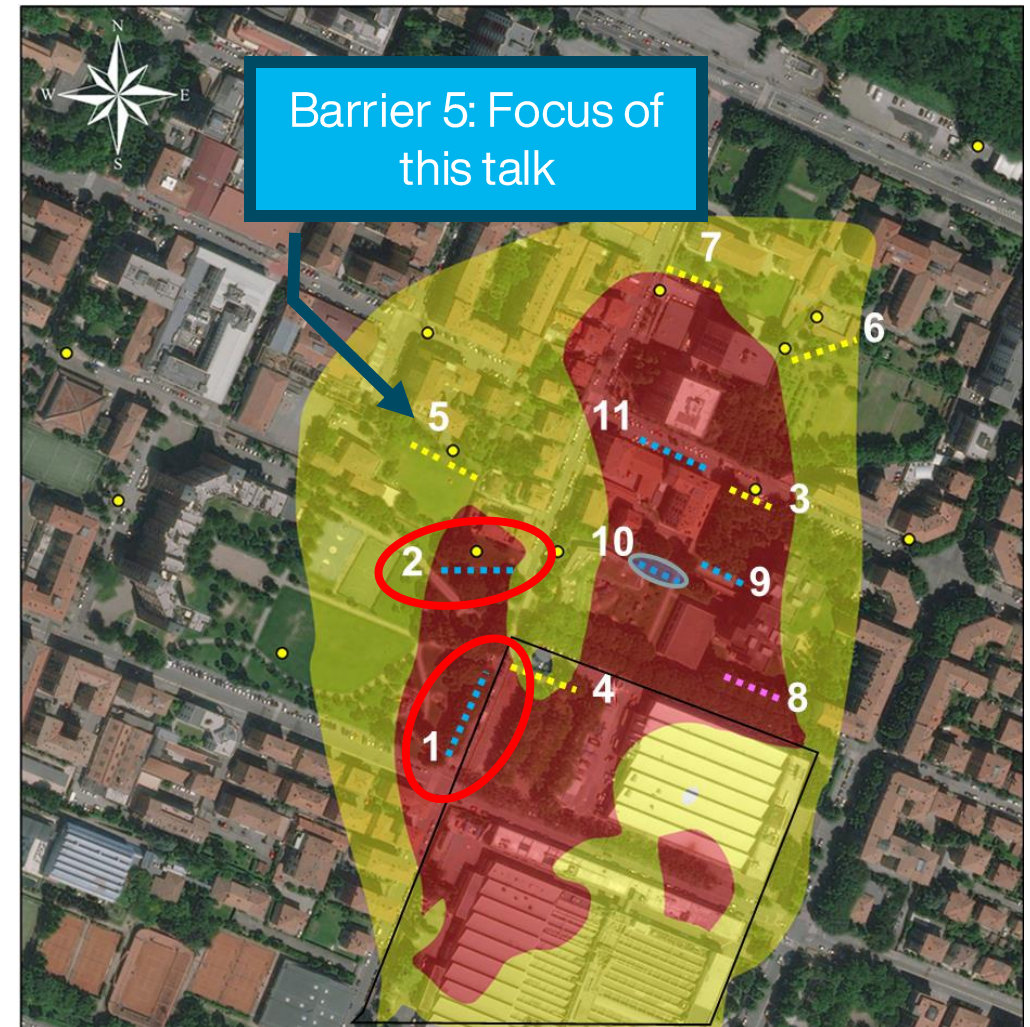
PCE Marzo 2015



Graphic: PCE plume map, March 2015 — Source: TAUW Italia / Sapienza Università di Roma, REGENESIS webinar (Petrangeli, 2021).

Plume-wide remediation master plan

- Eleven interventions over seven years, sequenced by concentration band across the city.
- A city-wide master plan was developed for the off-site plume
- Originally nine treatment areas, later expanded to eleven, phased over seven years
- Interventions 1 and 2 use coaxial groundwater circulation (in-well sparging)
- Those two systems removed 56.4 kg and 45.9 kg of PCE respectively
- Most remaining areas use permeable reactive barriers
- Barrier 5 sits in a church oratory garden within this wider programme



Graphic: intervention master-plan map — Source: TAUW Italia / Sapienza Università di Roma, REGENESIS webinar (Petrangeli, 2021).

$C < 100 \times CSC$ (MNA)

$100 \times CSC < C < 1000 \times CSC$
(Biotic/Abiotic Interventions)

$C > 1000 \times CSC$ (Physical Interventions)

Barrier 5: Key design challenges

- Thin, deep, cemented ground beneath a church oratory garden ruled out a standard barrier design.
- City-centre location with restricted access and working space
- Treatment beneath a church oratory garden used by the community
- Thin (approx. 1 m) treatment horizon at around 24 m depth
- Cemented soils prevented conventional direct-push advancement
- Aerobic aquifer where natural attenuation was not taking place
- Strict oversight, with No Further Action status as the goal



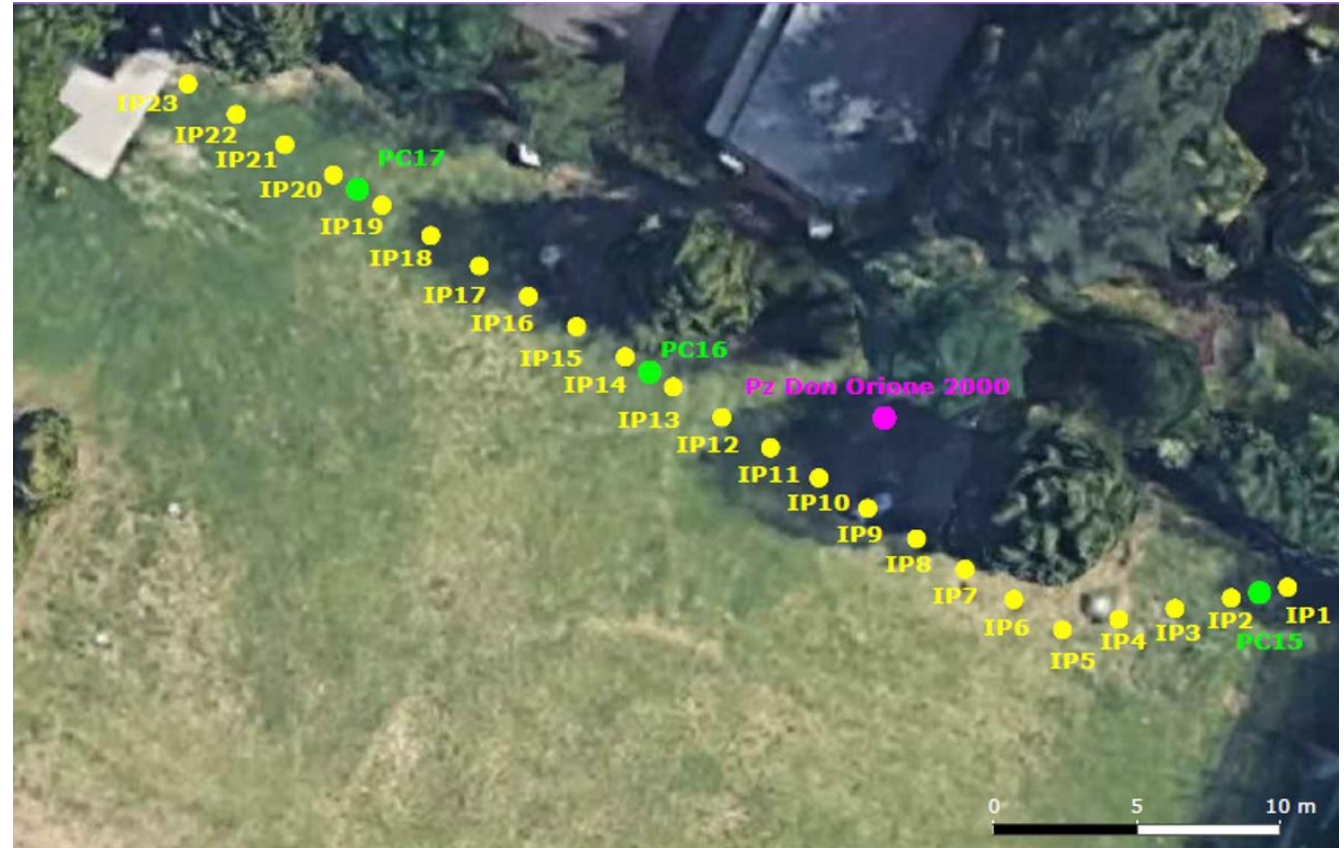
Barrier 5: investigation and design

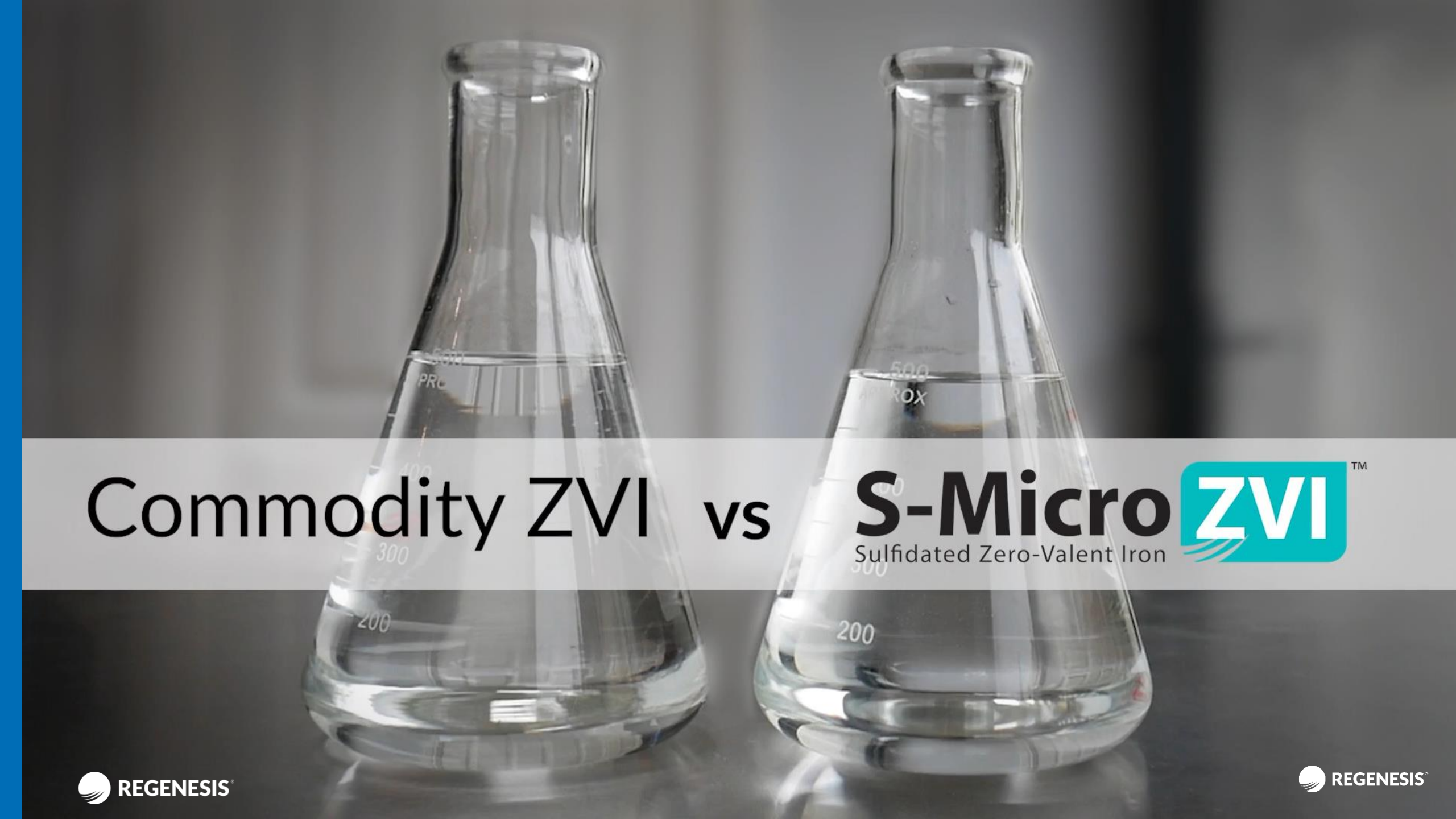
- A 46 m barrier of 23 injection points, each pre-cored to find the saturated interval and allow DP injection.
- Baseline: PCE 300 $\mu\text{g/L}$, TCE 10 $\mu\text{g/L}$, trichloromethane 10 $\mu\text{g/L}$
- 46 m ISCR–CAC barrier of 23 direct-push points at 2 m spacing
- Every point pre-cored with a 101 mm rig through cemented soil
- Pre-coring fixed depth and thickness of the interval at each point
- Monitoring wells added along and downgradient (PC15, PC17, POC)



Treatment technology

- Sorption stops the plume immediately; sulfidated iron destroys what is captured.
- PlumeStop colloidal activated carbon co-applied with S-MicroZVI
- Adsorption: sub-2 micron carbon coats the aquifer and halts contaminant flux
- Transformation: sulfidated iron degrades contaminants to ethene and ethane
- Regeneration: abiotic destruction of the contaminants clears the carbon sites
- Dosing per point: 52–100 kg PlumeStop, 39–80 kg S-MicroZVI





Commodity ZVI

vs

S-Micro
Sulfidated Zero-Valent Iron



Reactivity - Sulfidation

ZVI also reacts with water = H_2 which results in:

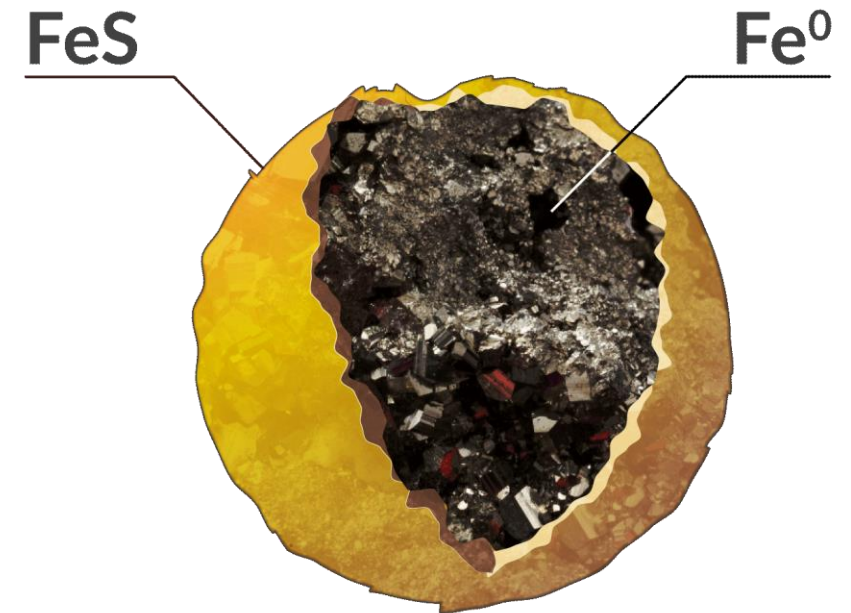
- Passivation
- Decreased persistence
- Less treatment of the contaminant

Answer = sulfidate the ZVI surface

“Coats the surface of the ZVI particle with iron sulfide”

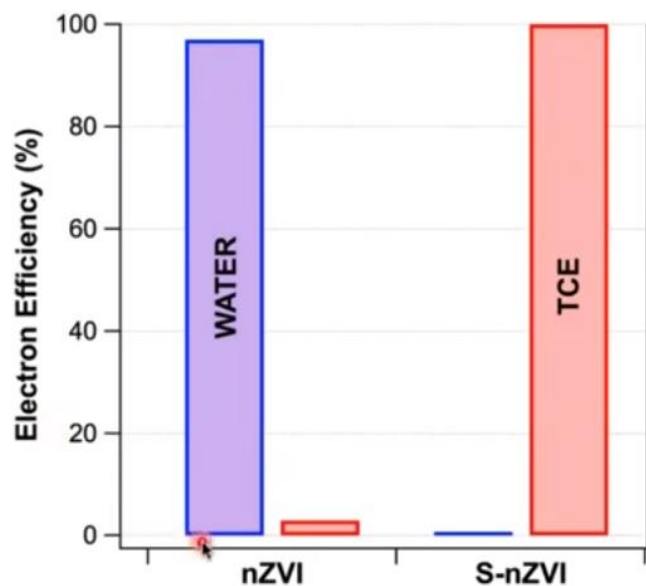
Results in an increase in Electron Efficiency (EE):

- Minimizes reaction rate with water
- Maximizes reaction rate with contaminants

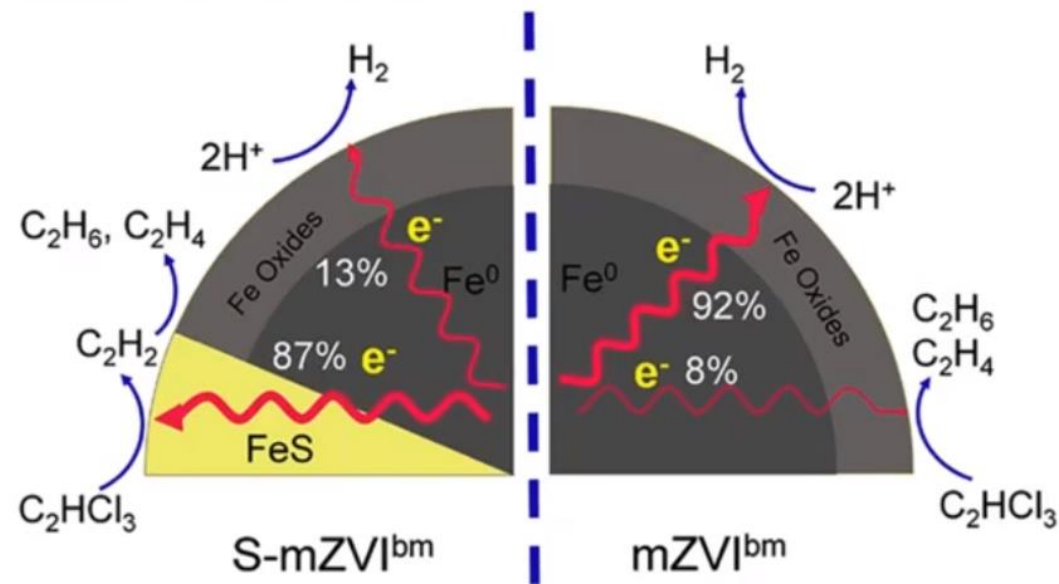


Reactivity - Sulfidation

Sulfidation enhances reaction rate with chlorinated ethenes



Fan, O'Brien, et al. (2016)
Env. Sci. Technol. 50: 9558-9565
*Sulfidation of nZVI for Improved
Selectivity during ISCR*



Gu, Wang, He, et al. (2017)
Env. Sci. Technol. 51: 12653-12662
*Mechanochemically Sulfidated mZVI:
Pathways, Kinetics, Mechanisms, Selectivity*

Ref: Dr Paul Tratnyek, Oregon Health and Science University

What is it?

- Liquid activated carbon
- Particle sizes 1 – 2 μm
- Suspended as a colloid in a polymer solution
- Distributes widely under low pressure
- Provides extremely fast sorption sites
- Converts underlying geology into purifying filter



PlumeStop attachment to the aquifer

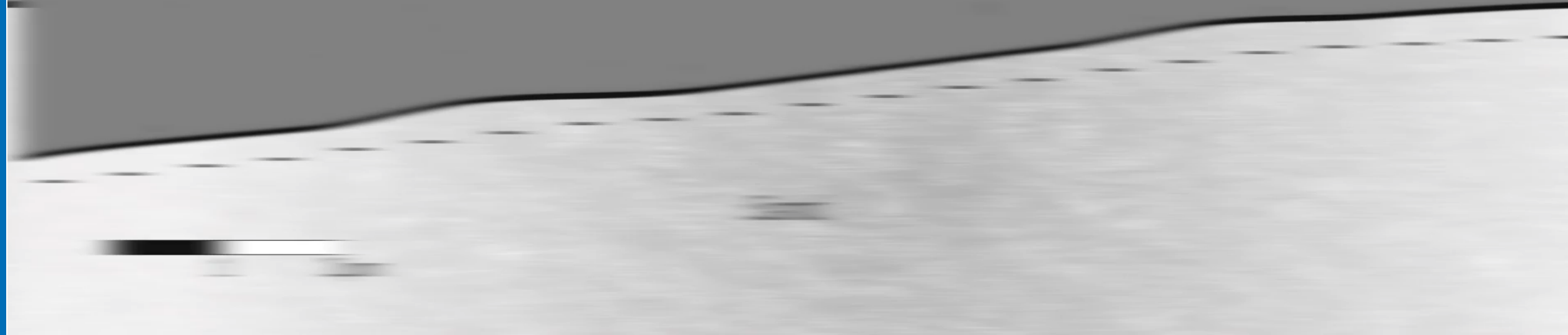
Sand

Sand

Sand

10 20µm

Plume Stop attachment to the aquifer



Sorption of chlorinated solvents

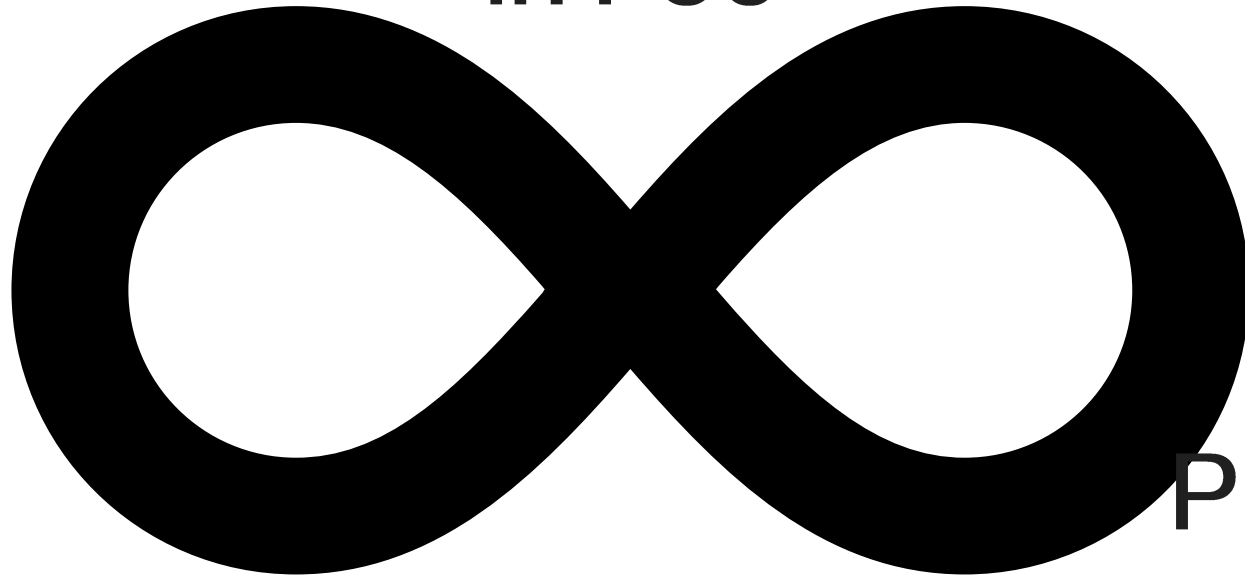
Sand

10 20µm

PlumeStop – Permanent Aquifer Chemistry Modification

Increase
in Foc

Sorption
capacity



Plume
retardation

Installation approach

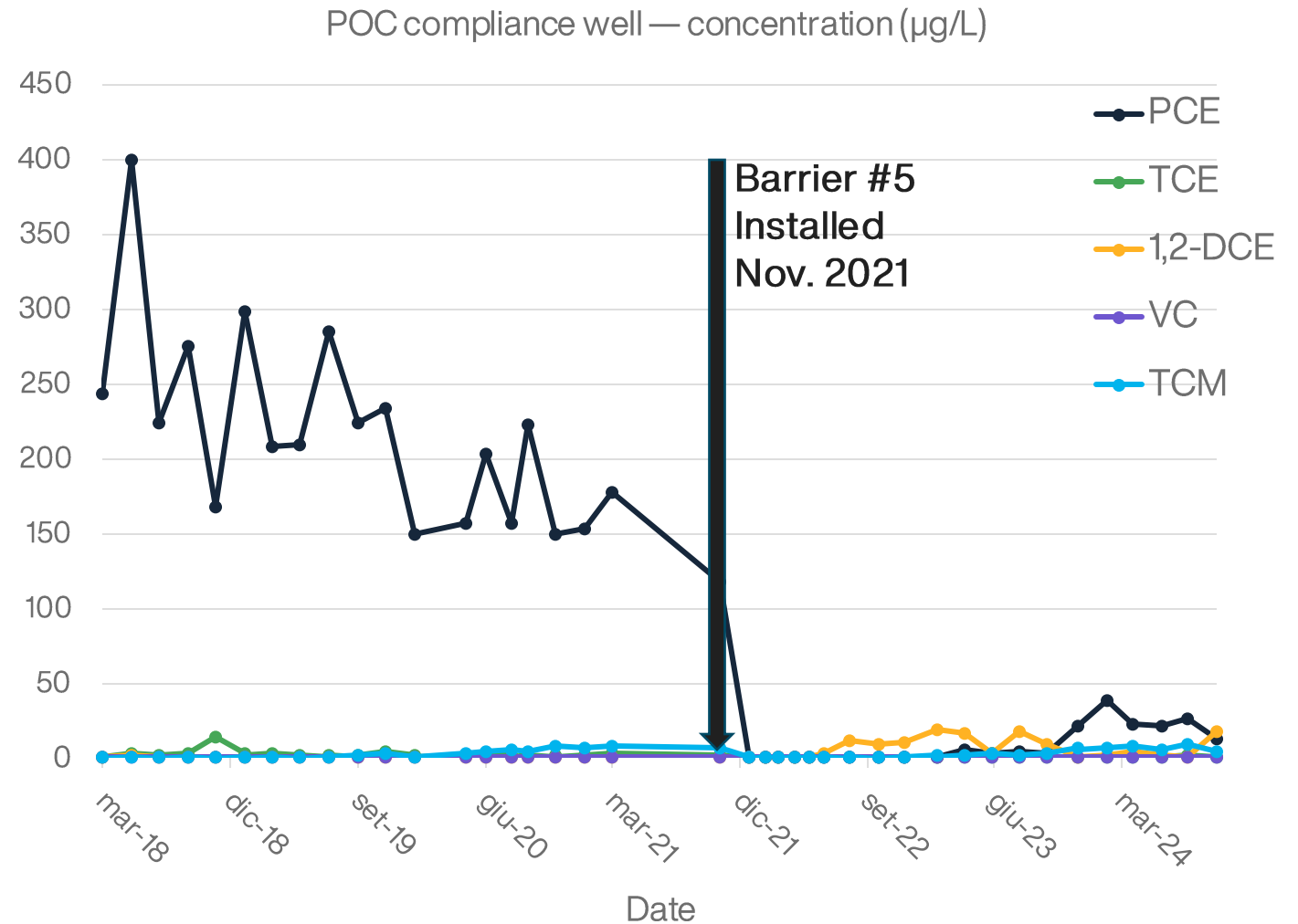
- One mobilisation, eight working days, low-pressure injection to protect the setting.
- Cored holes backfilled with cement above and sand across the injection interval
- Direct-push rig advanced through the prepared column into the aquifer
- Injection depth approximately 23.8–24.8 m, adjusted per point on site
- Low-pressure injection below 2 bar, about 620 L per point (up to 1,200 L)
- Confirmation testing verified interlocking radii of influence



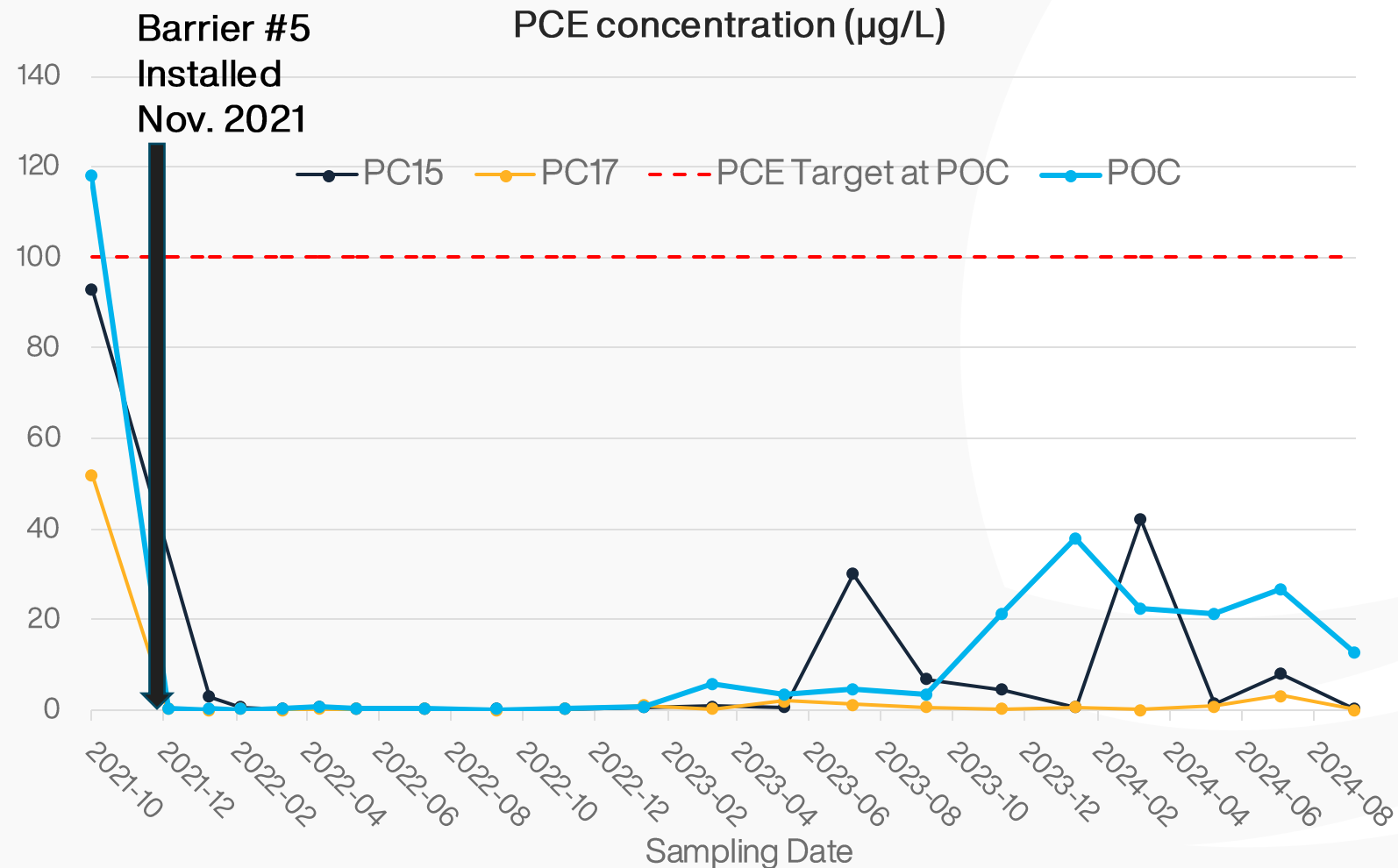
Performance

PCE down two orders of magnitude and held below target through three years of bi-monthly monitoring.

- Compliance well fell below the 100 µg/L target: two orders of magnitude
- Non-detect immediately after application, settling to about 96% reduction
- Sustained through three years of bi-monthly monitoring
- Minimal cis-1,2-DCE or vinyl chloride daughter products detected
- Trichloromethane also reduced; in-barrier wells PC15 and PC17 agree
- Benchmarks: 1.1 µg/L statutory standard, 100 µg/L management target



PCE at all downgradient wells



- Barrier 5 installed November 2021
- PC15 and PC17 in-barrier wells fall to near non-detect within weeks
- POC compliance well holds below the 100 µg/L target throughout
- Minor rebounds in 2023–24 stay an order of magnitude below target
- Bi-monthly monitoring sustained for close to three years
- Duplicate monitoring by the Italian EPA

Questions

Project Team

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