Remediation of Chlorinated Ethenes Plume in Denmark by Retardation and Enhanced Biodegradation – Lessons Learned

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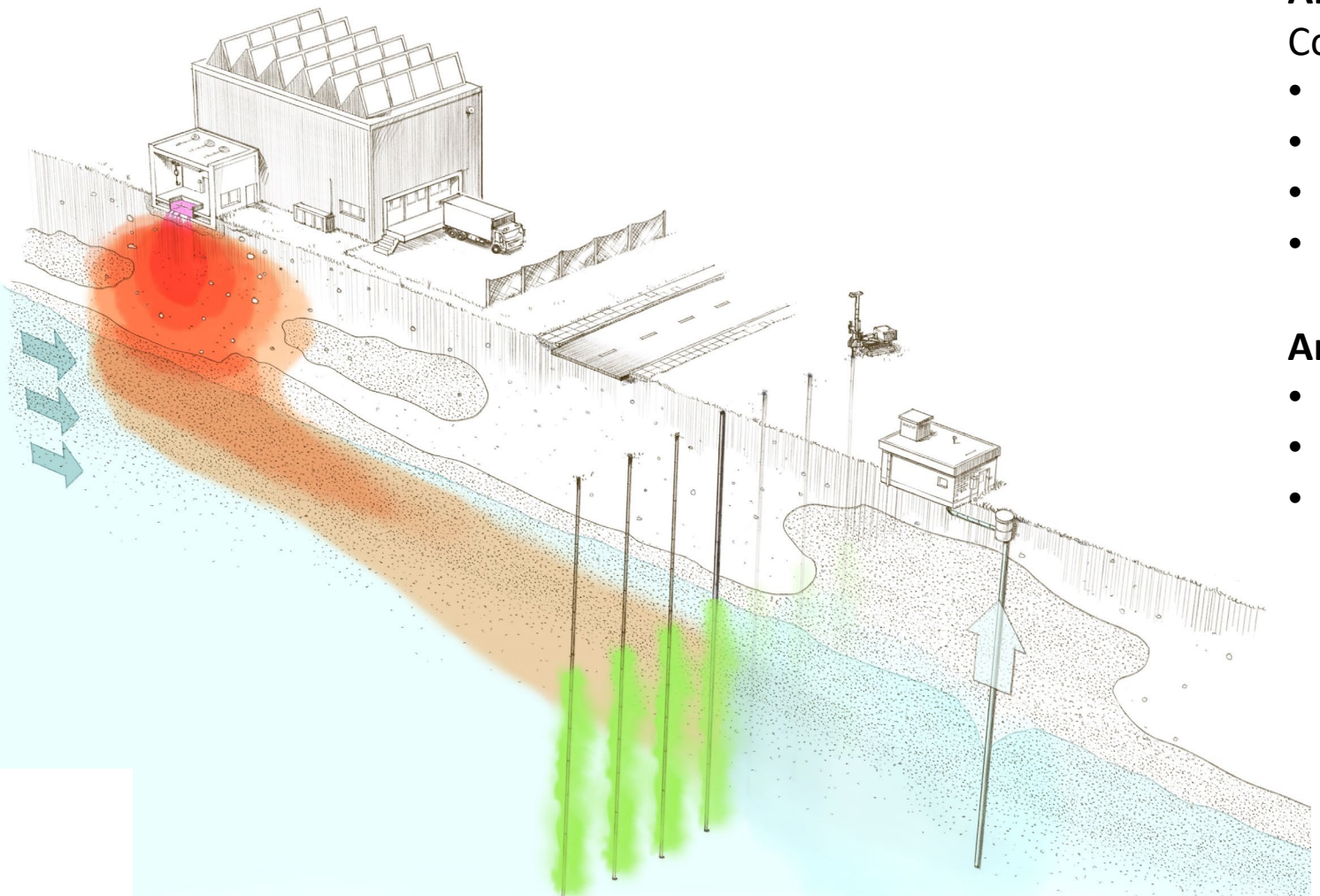
- Mette Broholm, Annika S. Fjordboege, DTU Sustain
- Gareth Leonard, Regenesis
- And many more!

Introduction



Motivation

- Alternatives to Pump & Treat?
- Effective, economic, *sustainable*
- Passive in situ techniques attractive

Aim of study

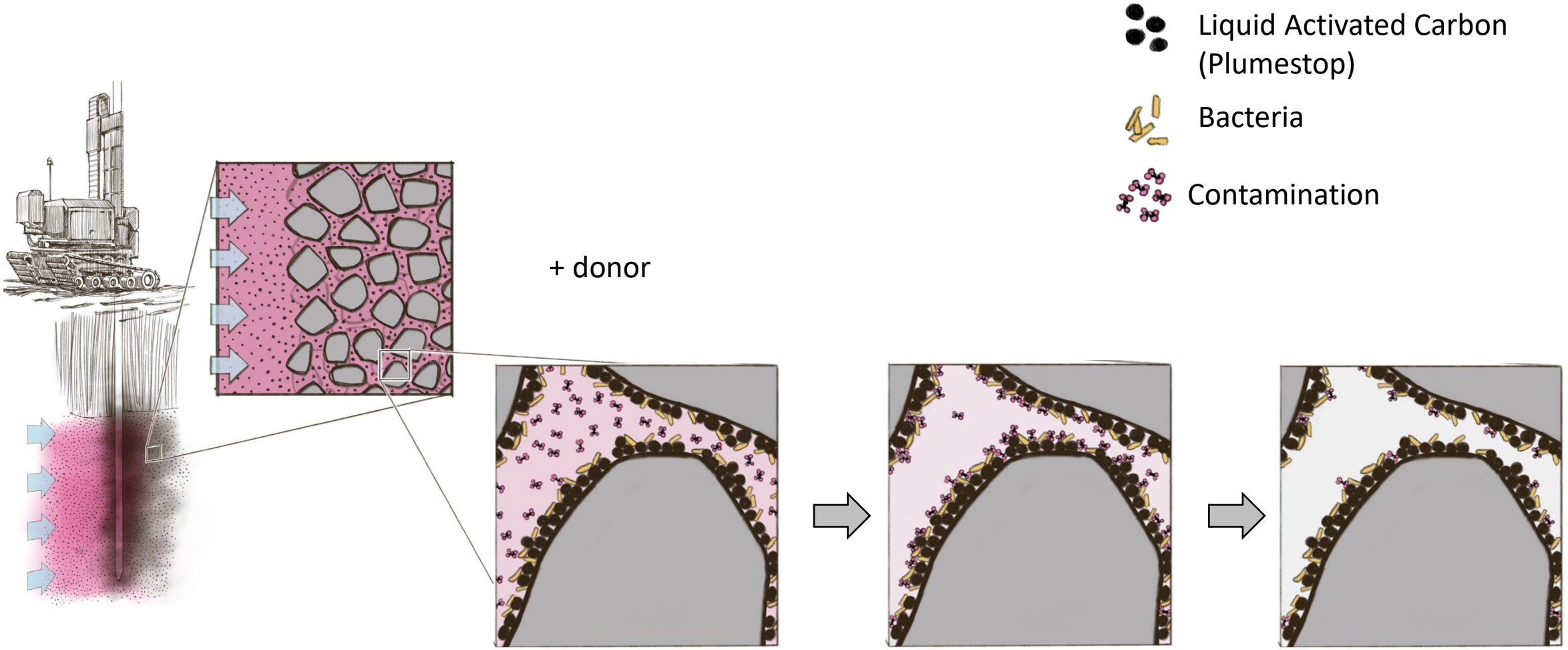
Comprehensive proof of concept

- Distribution of amendments
- Documentation of processes
- Risk reduction
- Recommondations for future use

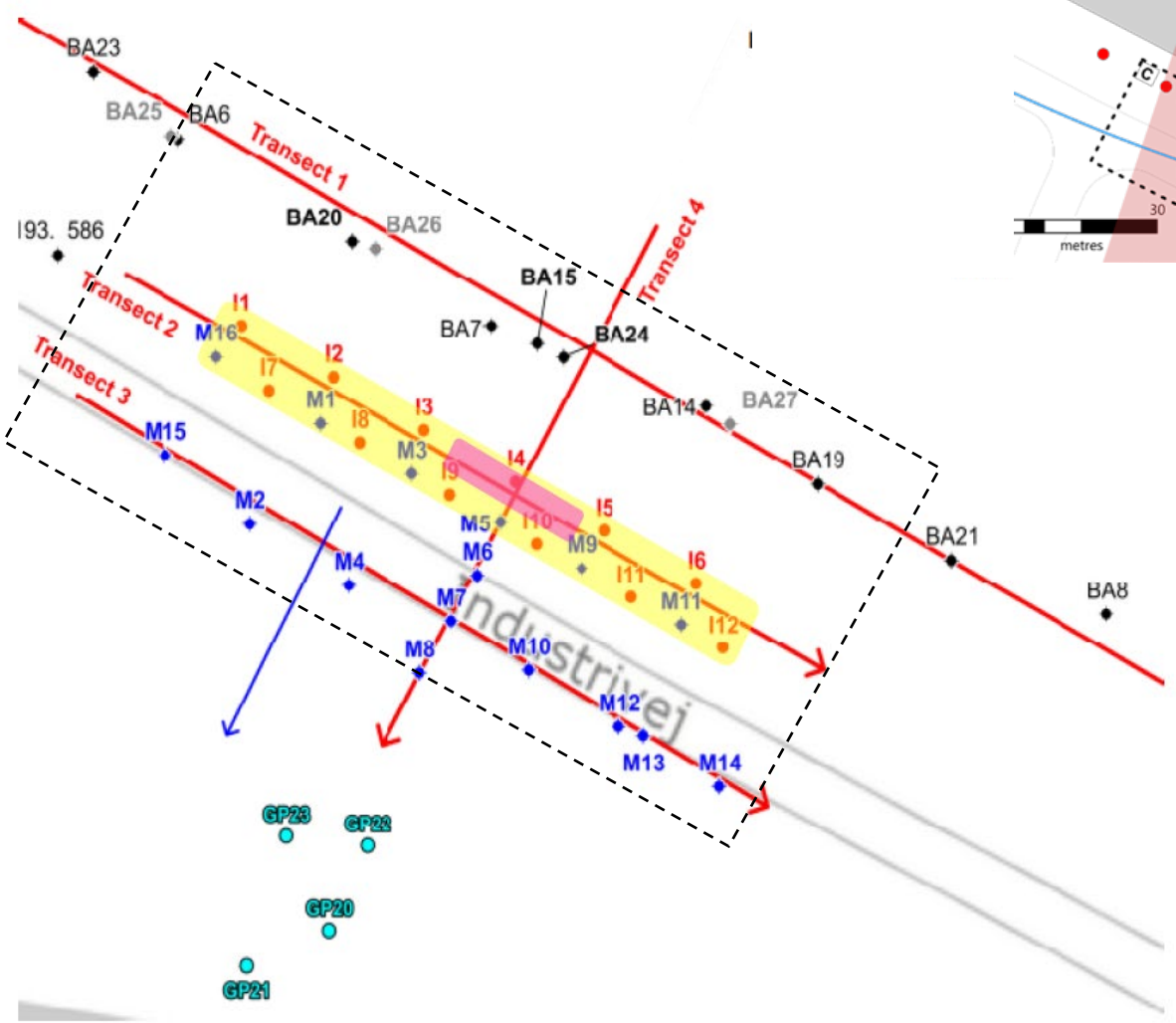
Ambition with this talk

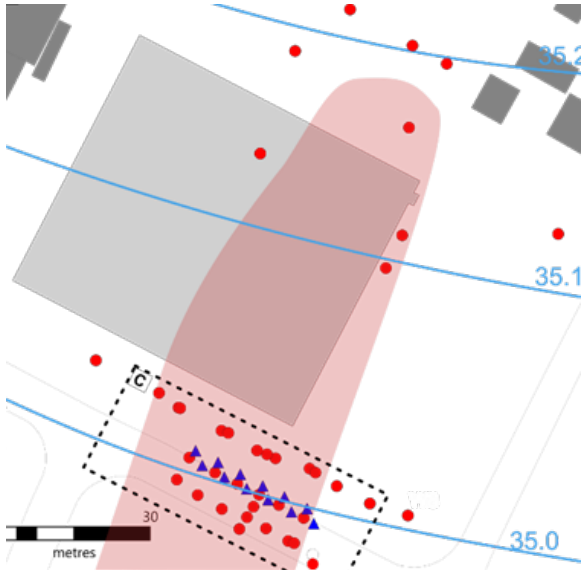
- Illustrate that it works
- Highlight some important challenges
- Draw your attention to our massive dataset

Concept – combined sorption and degradation



Pilot test site





Typical Danish situation

- Sandy aquifer
  - K= 2-6 x 10^{-5} m/s
  - V_p: 5-30 m/yrs
- Plume
  - TCE: 500-1200 ug/l
  - 30 m wide, 12-21 mbs
  - Mass Flux: 150-300 g/yrs

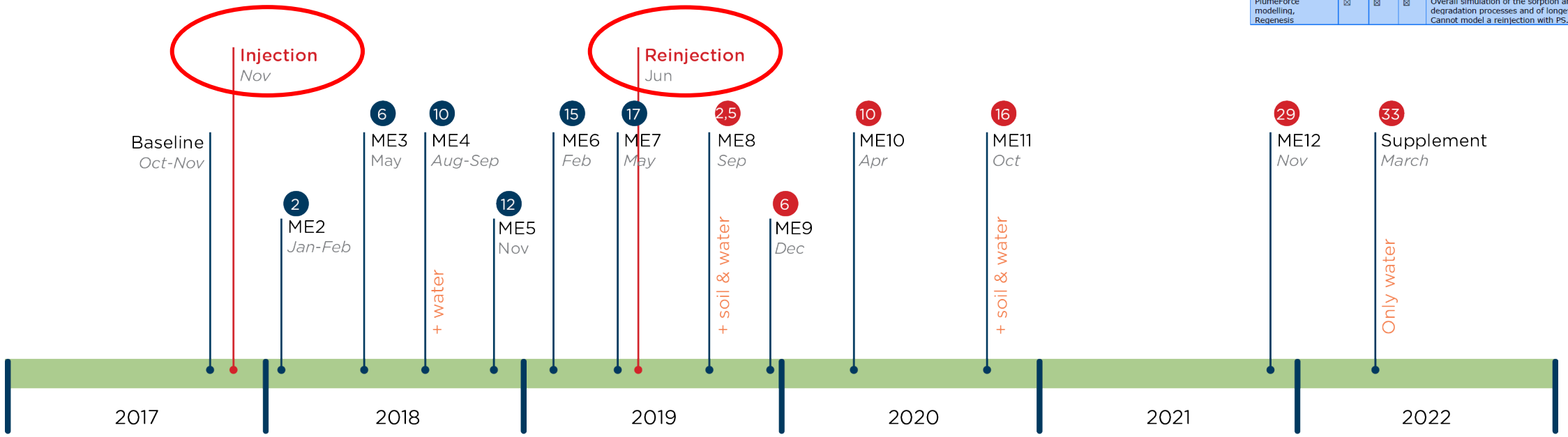
A few pictures

Massive dataset

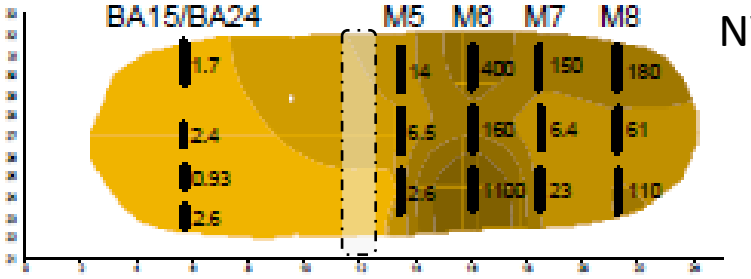
- + 70 monitoring wells
- 13 monitoring rounds (and counting)
- Supplementary laboratory, field tests and modelling
- 6 student projects (incl. MSc and PhD)
- Multiple documentation tools

Documentation tools

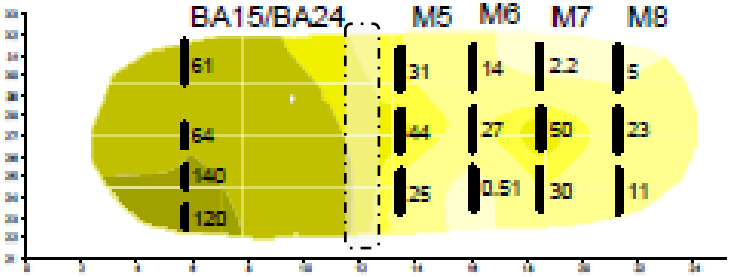
Method	Degr.	Sorp.	Dist.	Usefulness	App
Treatability tests, DTU	☒	☐	☐	Used to assess, quantify and characterize the degradation in the presence of PS.	7a
Biodegradation screening test, Regenesis	☒	☐	☐	Factors (DHC, donor, nutrients) influencing the degradation process were studied.	7c
Column tests, Regenesis	☒	☒	☐	Sorption and degradation of CE in the presence of PS was evaluated using abiotic and biotic PS columns.	7b
Water sampling (traditional)	☒	☒	☒	Samples were collected for visual PS analysis and sent to the lab for further chemical or microbial analysis. Very useful.	
Depth discrete water sampling, Geoprobe	☒	☒	☒	Discrete sampling was extremely good at evaluating the effectiveness of the sorption, distribution of PS and degradation based on composition of chlorinated ethenes	
Soil from tradition borings	☒	☒	☒	Samp analy chem	
Soil cores	☐	☒	☒	Soil c provi over were tests	
Traditional groundwater analyses	☒	☒	☒	Variou CE, N sorpti donor	
Traditional soil analyses	☒	☒	☒	Variou conce degra PS	
TOC analyses	☐	☒	☒	Docu not su	
EC logs	☐	☐	☒	Monit predi	
CSIA	☒	☐	☒	Docu there Deter and p Revea amen	
Microscopy, Geosyntec	☒	☐	☐	Used forma CE.	
QuantArray, Microbial Insights	☒	☐	☐	Analyses were conducted to measure the presence of contaminant degrading bacteria	
Viable DHC, Microbial Analysis	☒	☐	☐	Complimentary analysis to measure the proportion of viable bacteria	
Ground water levels measurements	☐	☐	☒	Measures changes in the groundwater table.	
Slug tests	☐	☐	☒	Documentation of potential changes in the groundwater flow due to the injected PS and biological processes	11d
Grain size distribution	☐	☐	☒	Forms the basis for an estimation of pore throat sizes to assess whether the amendments are actually of a size to be distributed in the aquifer material	11a
LL-MIP	☐	☐	☒	Used to delineate CE plume vertically and horizontally.	11g
OIP	☐	☐	☒	Optical image of treatment zone to distinguish between natural soil and soil with PS. On this site with the PS dose used in the 1. injection it was not possible to discern PS from natural soil.	7g
Visual inspection of water and soil samples	☐	☐	☒	PS could visually be seen in some samples (valuable evidence of PS distribution), cannot be used to quantify the concentration.	11i
Sorption capacity, DTU	☐	☒	☒	Good at estimating where a significant amount of PS is present and the sorption capacity.	7h
PlumeForce modelling, Regenesis	☒	☒	☒	Overall simulation of the sorption and degradation processes and of longevity. Cannot model a reinjection with PS.	7i



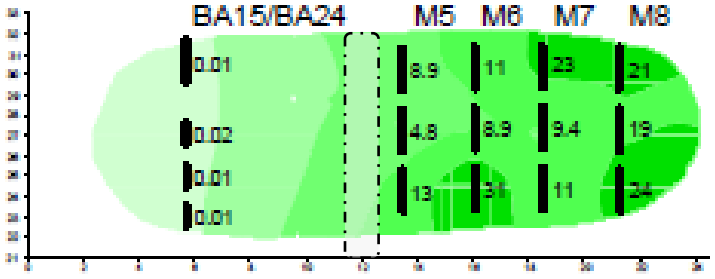
Distribution of amendments



NVOC

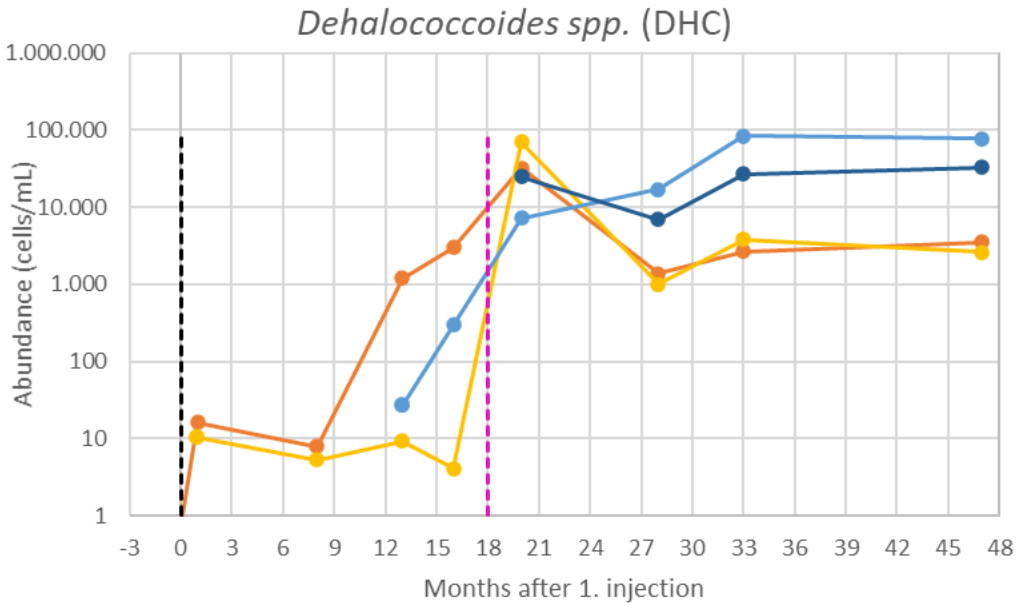


SO_4^{2-}



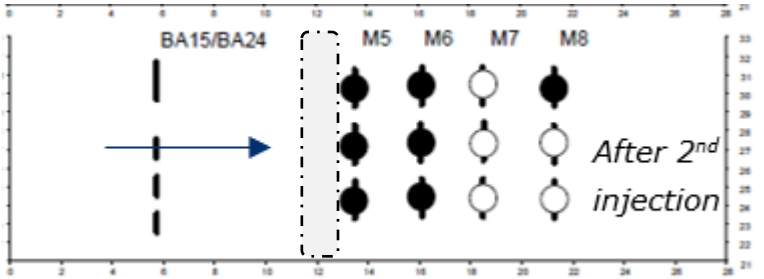
CH_4

upgradient → downgradient



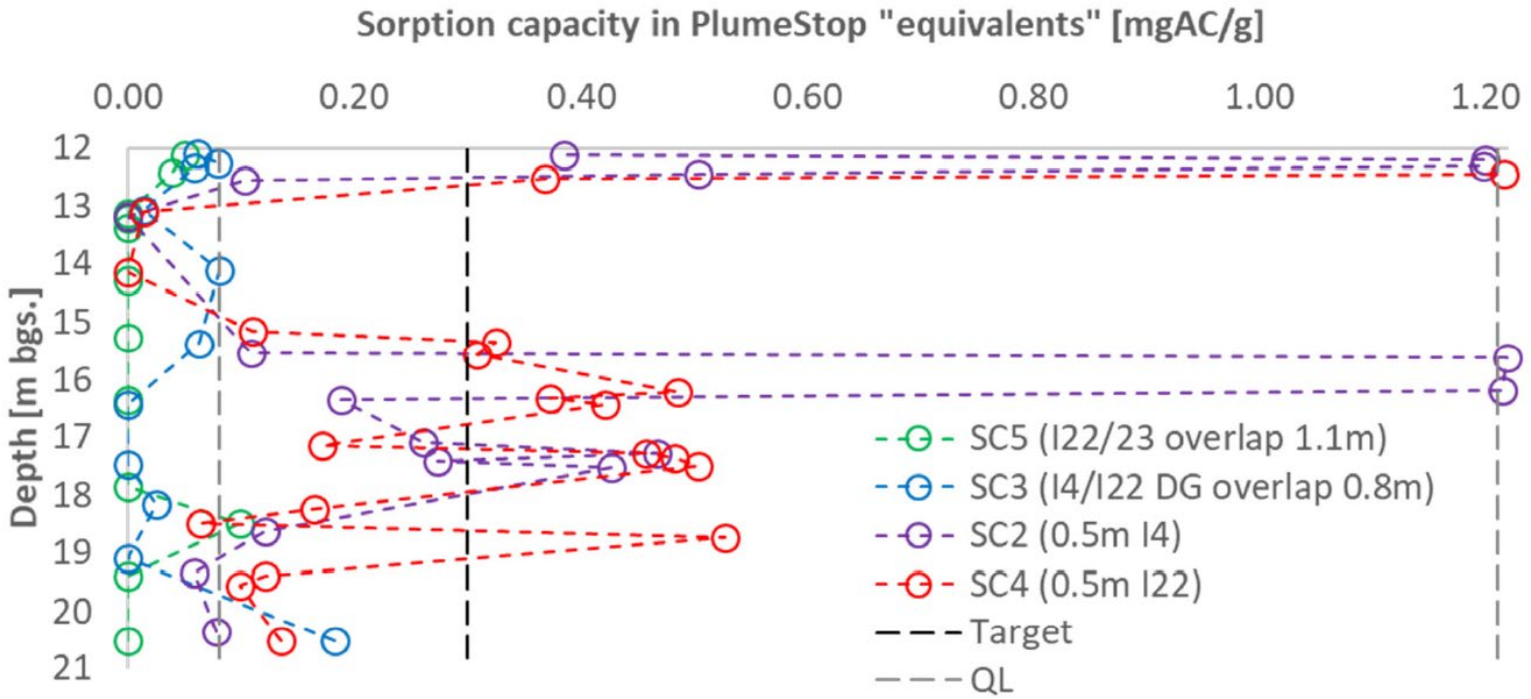
Dechlorinating bacteria

Distribution of amendments



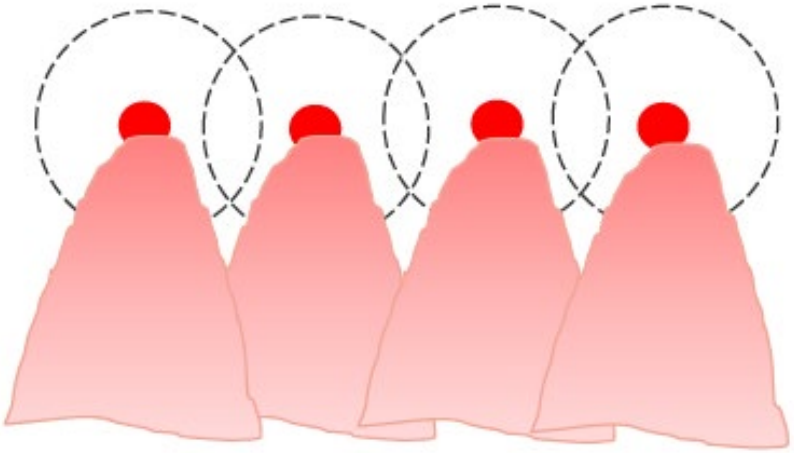
Water colour

Soil colour

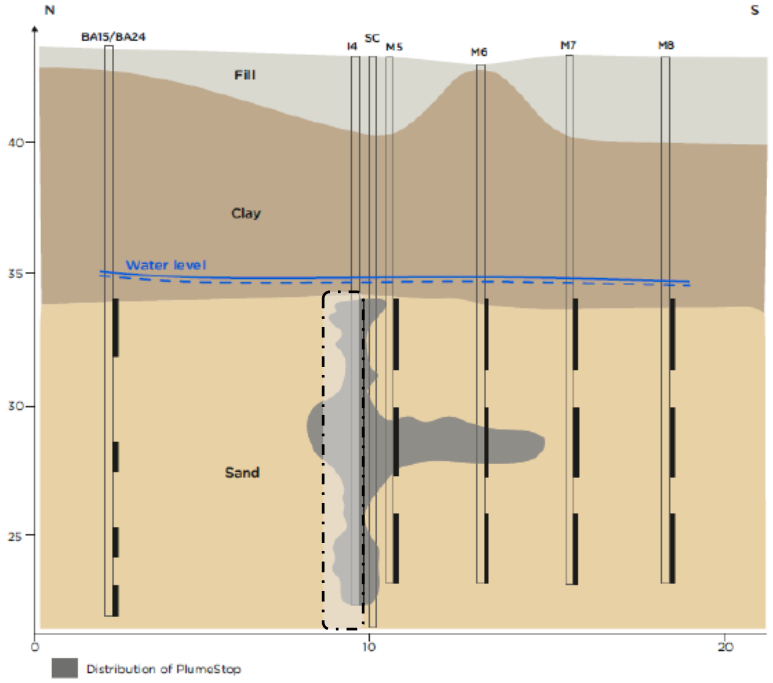


Conceptualized results of distribution

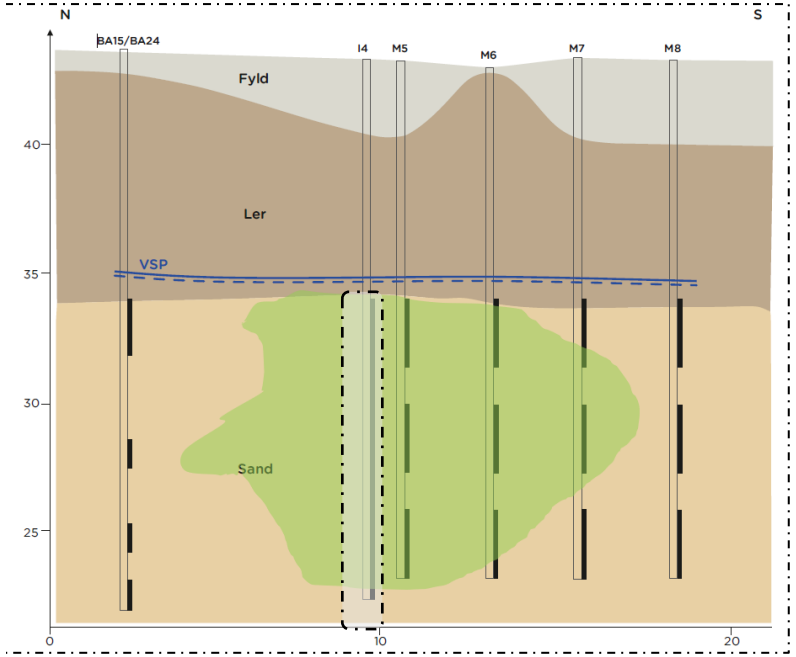
- Heterogeneous distribution
- ”plumes” rather than circles
- Distribution best in higher flow zones
- ”easy” to distribute donor
- Bacteria extends beyound injection zone



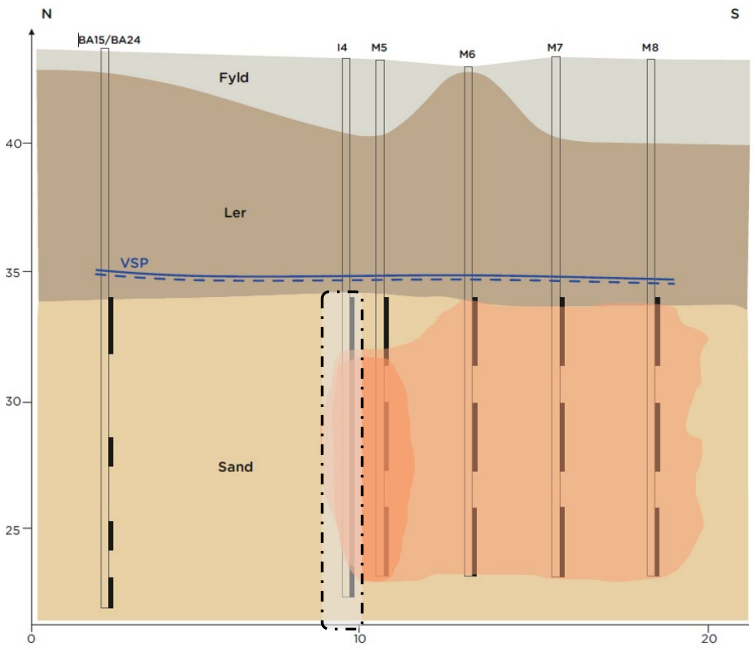
Liquid activated carbon (Plumestop)



Donor (NVOC)

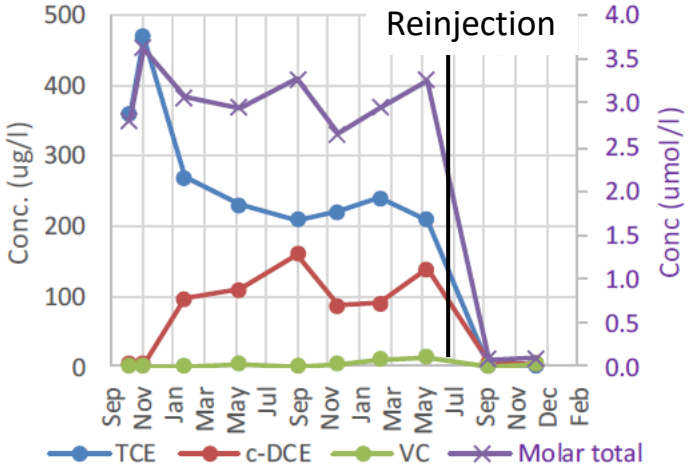


Bacteria (DHC)

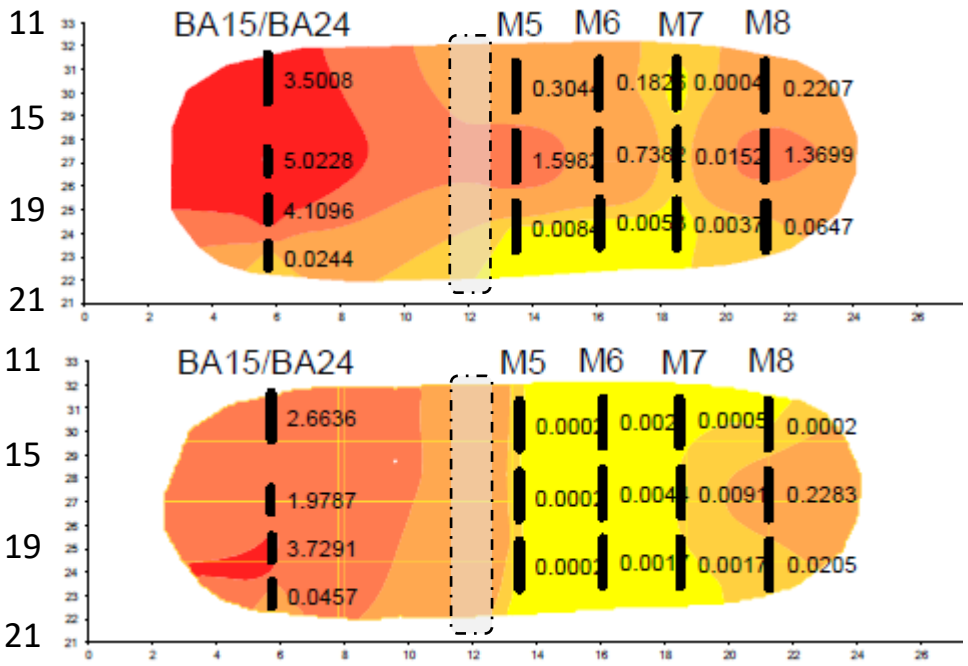


Sorption

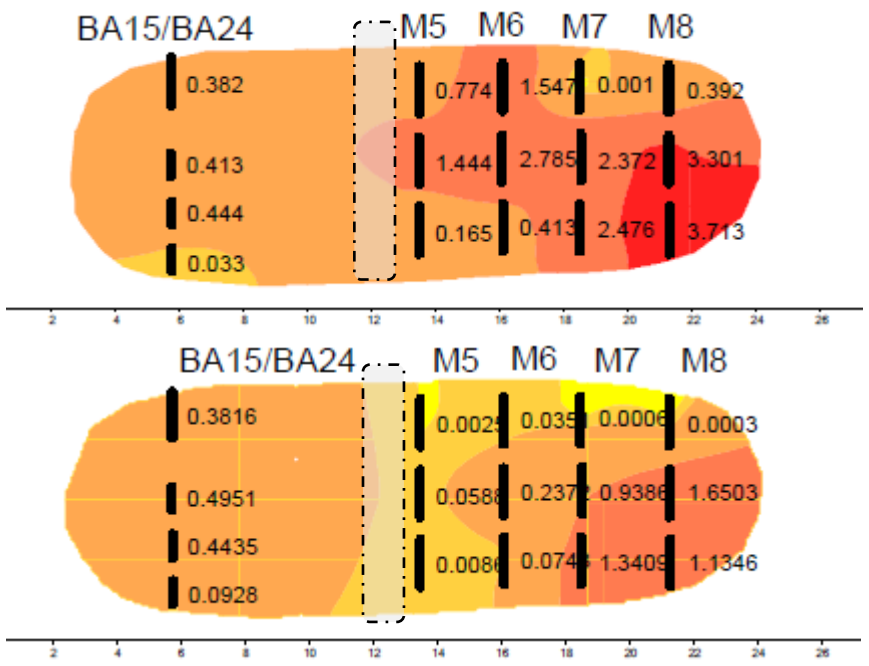
- Quick sorption of TCE
- Also (less) sorption of cis-DCE and VC, but more complicated interpretation

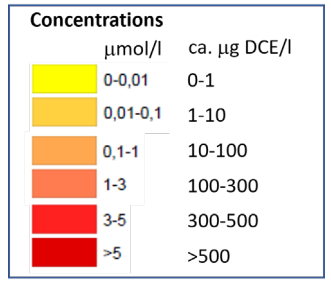


TCE



cis-DCE

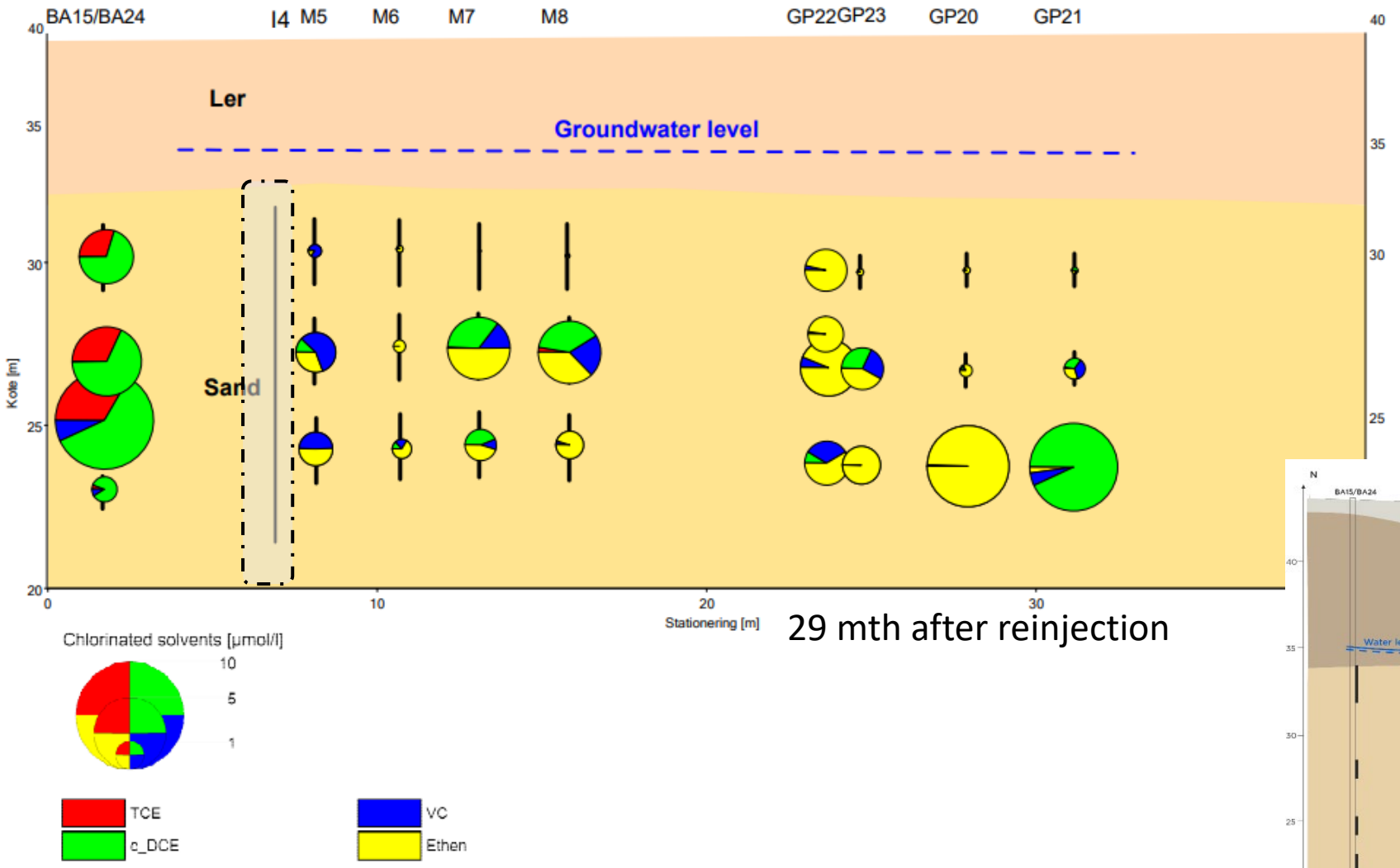




Before Reinjection

3 mth after reinjection

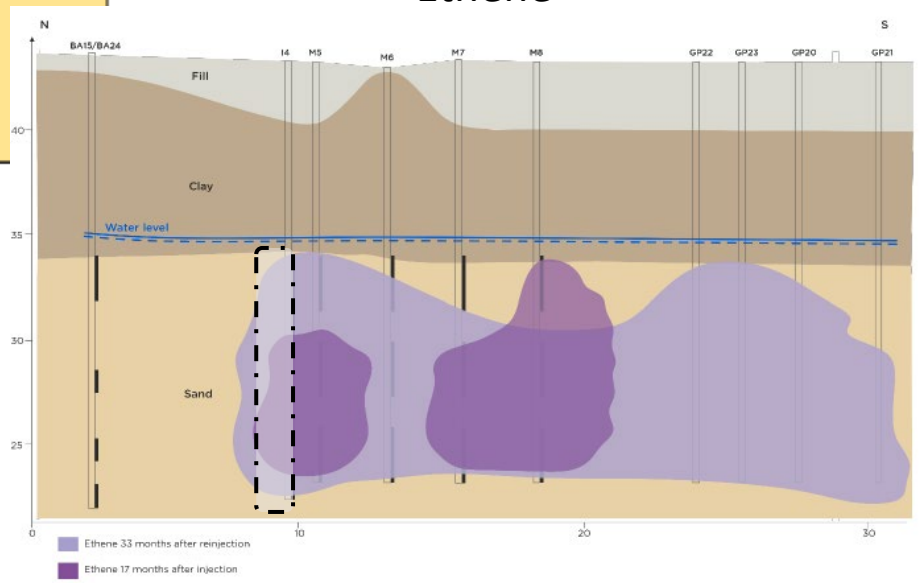
Degradation



29 mth after reinjection

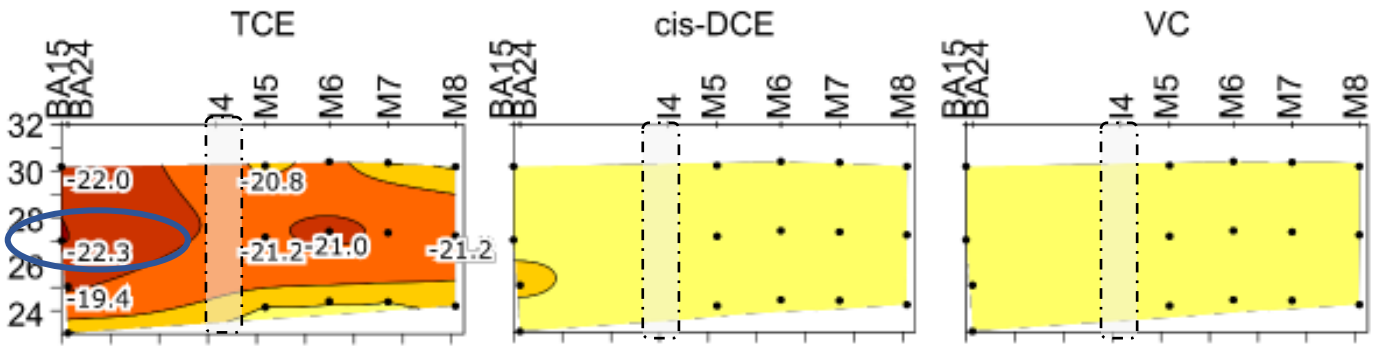
- Complete degradation downgradient
- (Effect has not reached lowest screen in GP21 due to slow water velocity)
- Donor has spread upgradient involving degradation to cis-DCE

Ethene

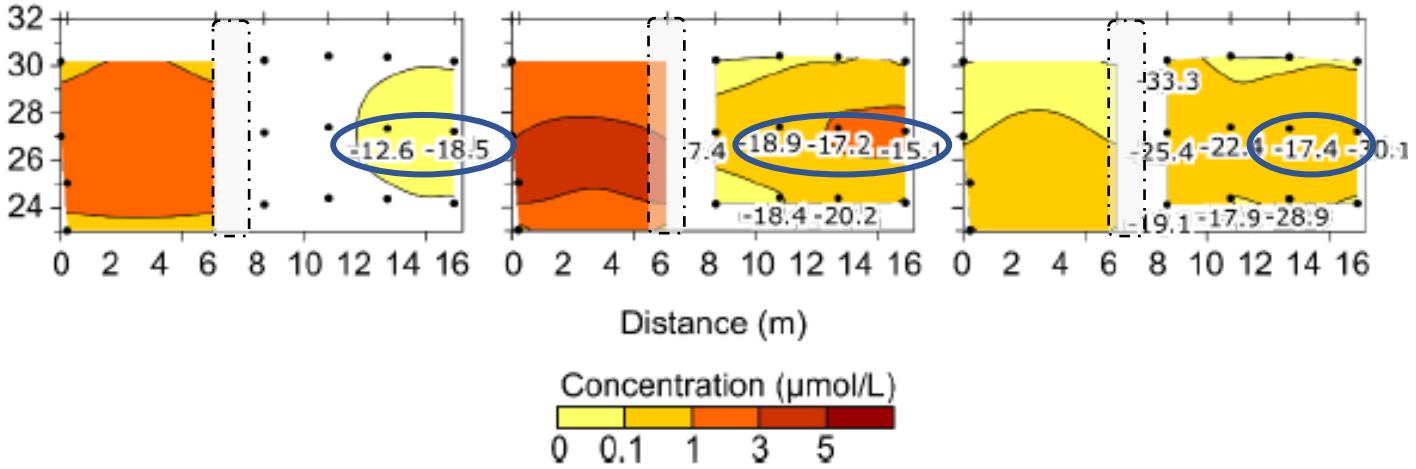


Degradation - CSIA

Baseline

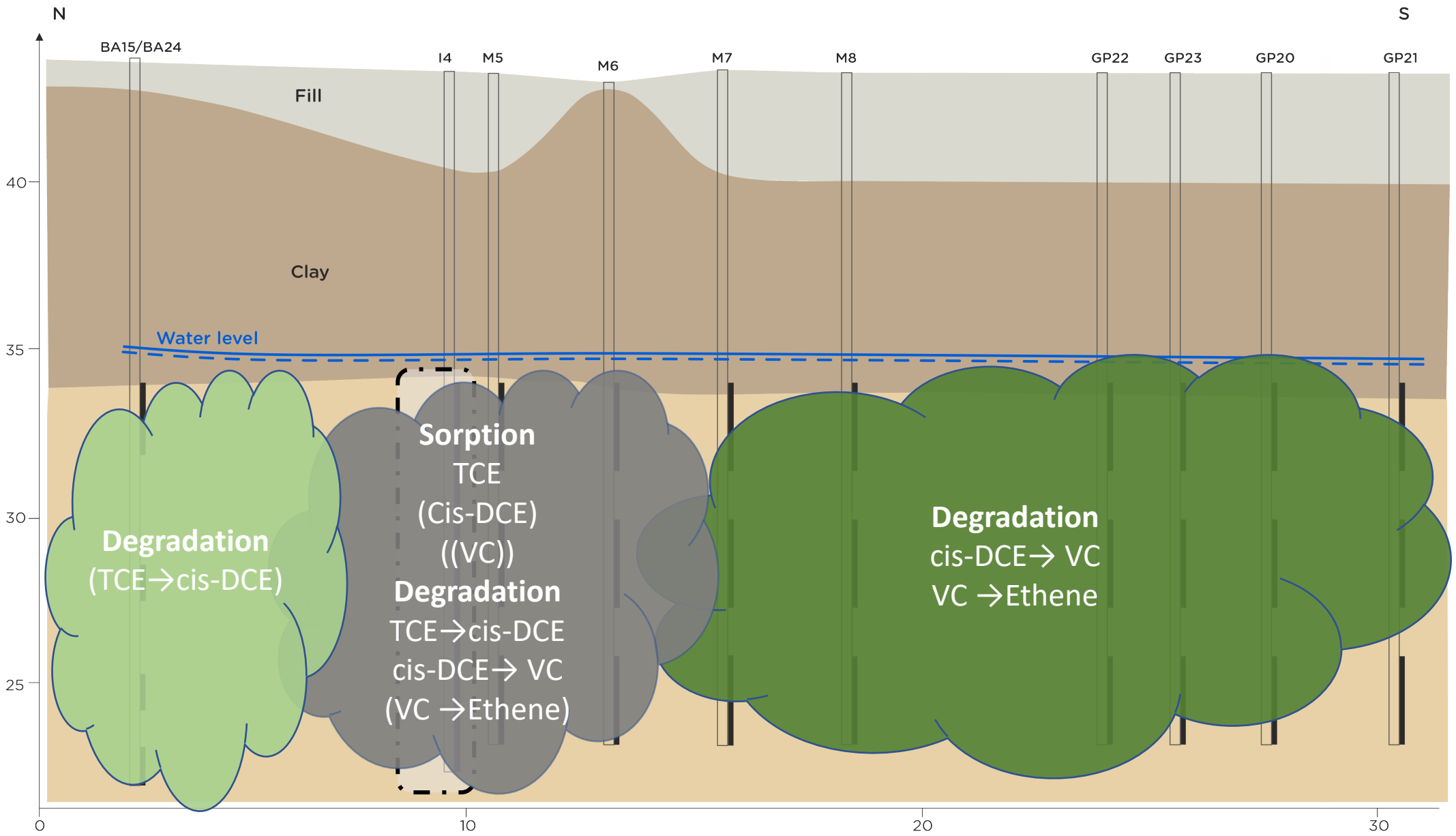


29 mth after reinjection



- Initial isotopic signature of TCE of -21 to -22‰
- Clear evidence of degradation of TCE and cis-DCE (enrichment in ^{13}C)
- CSIA shows both production and degradation of VC
- Analysis generally challenged by low concentrations

Revised conceptual understanding

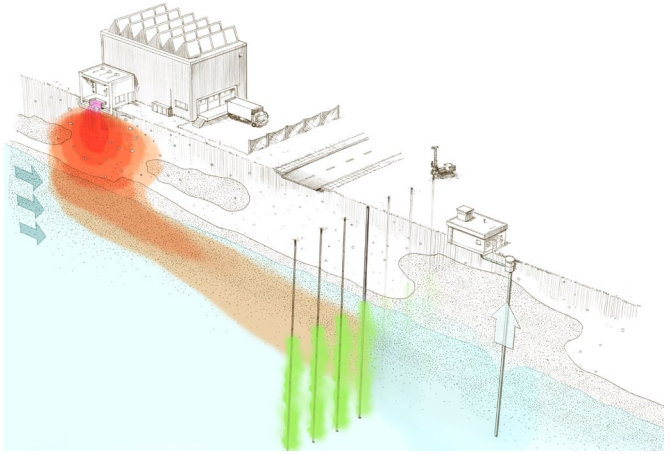


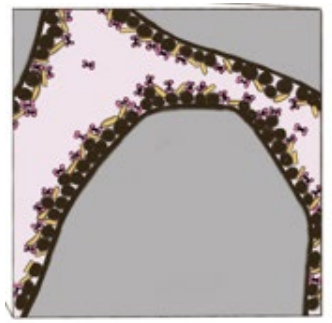
Lessons learned

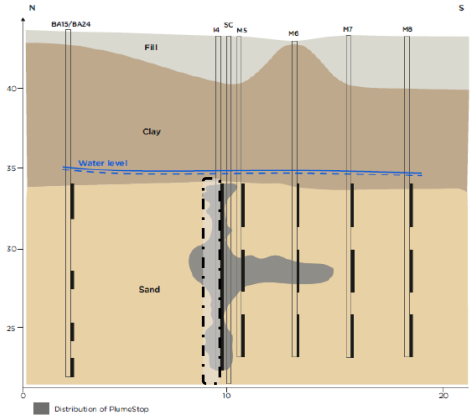
- In situ plume remediation by combined sorption and degradation works
  - processes proved
  - Risk reduction (>95% mass discharge reduction)

- Main challenges
  - Distribution of amendments
    - Especially liquid activated carbon and bacteria
  - Documentation

- Likely a more sustainable method compared to Pump & Treat

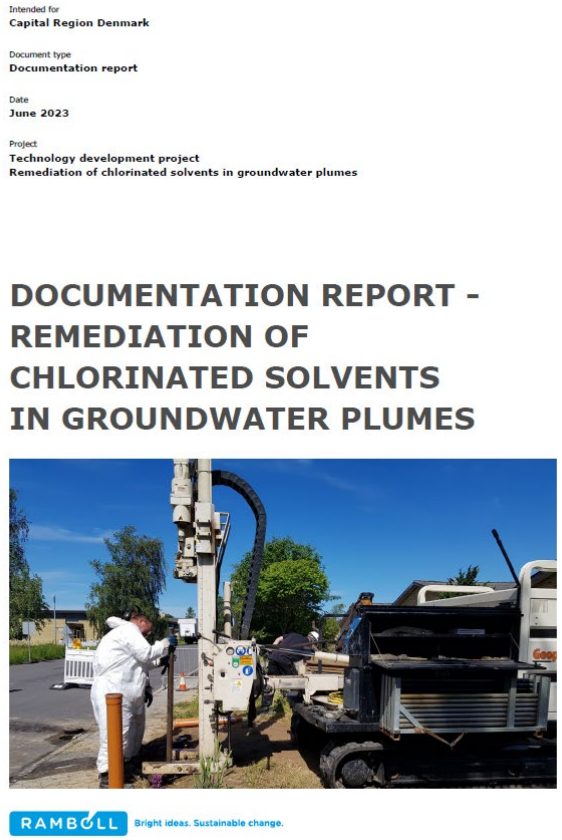






Recommendations

- Ensure adequate distribution
  - Monitor during injection
  - Accept non-homogeneous distribution
  - Expect reinjection
- ”Nurse” bacterial population
- Regenesis advise to co-inject ZVI
- Read our report



Intended for
Capital Region Denmark

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Documentation report

Date
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Project
Technology development project
Remediation of chlorinated solvents in groundwater plumes

DOCUMENTATION REPORT - REMEDIATION OF CHLORINATED SOLVENTS IN GROUNDWATER PLUMES

RAMBØLL Bright ideas. Sustainable change.

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