

The background image shows an outdoor industrial or construction site. On the left, there is a long, white, corrugated metal container. In front of it, a pallet is loaded with several blue plastic jerrycans. To the right, a white van is parked, facing the camera. The van has "www.logisticon.com" printed on its front and a yellow license plate that reads "16-BH-FB". A person is standing near the open back door of the container. The scene is set against a brick building and a dark sky.

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Site description: Gl. Kongevej, Copenhagen

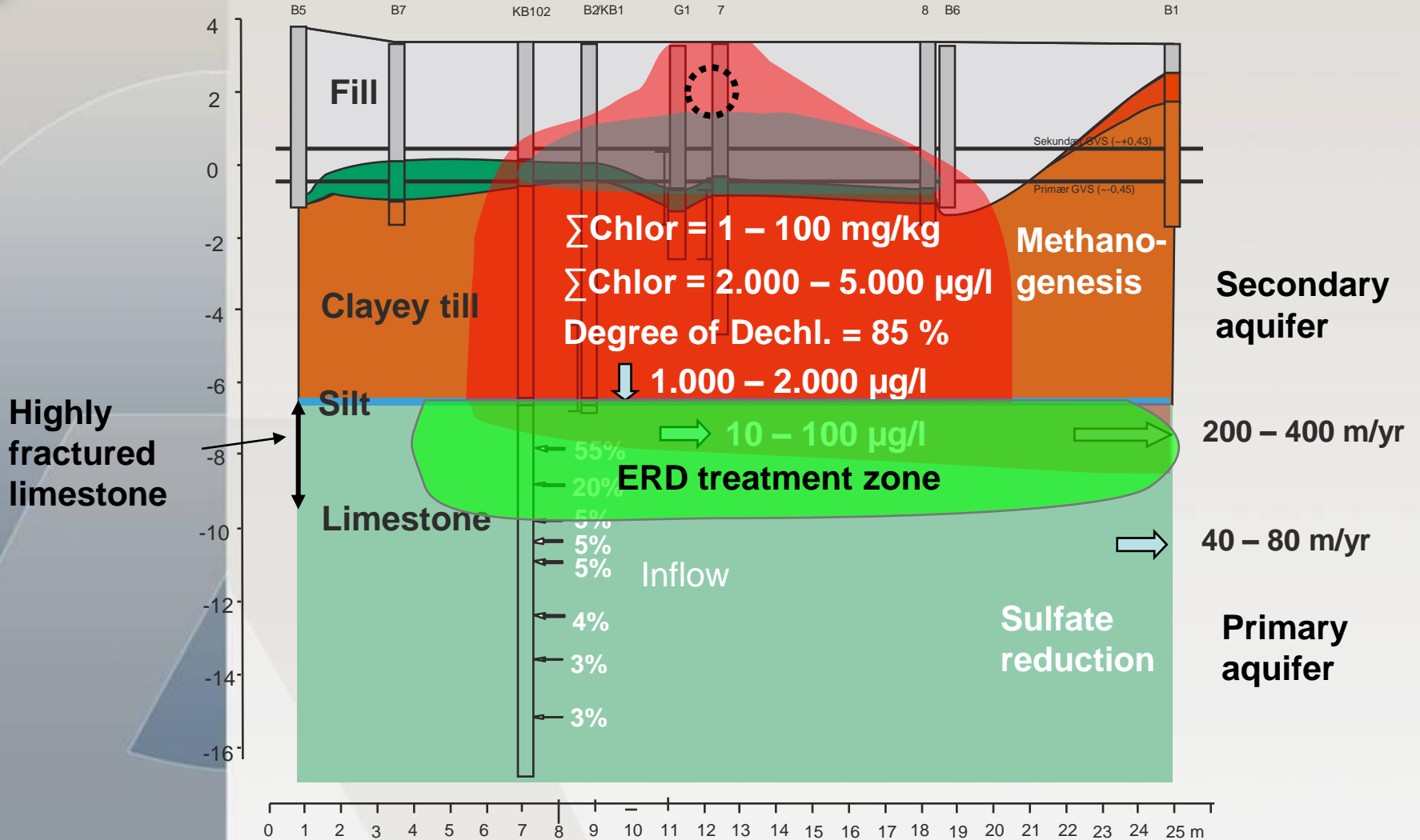
- Residential area of central Copenhagen
- Former dry cleaner

Underground parking lot

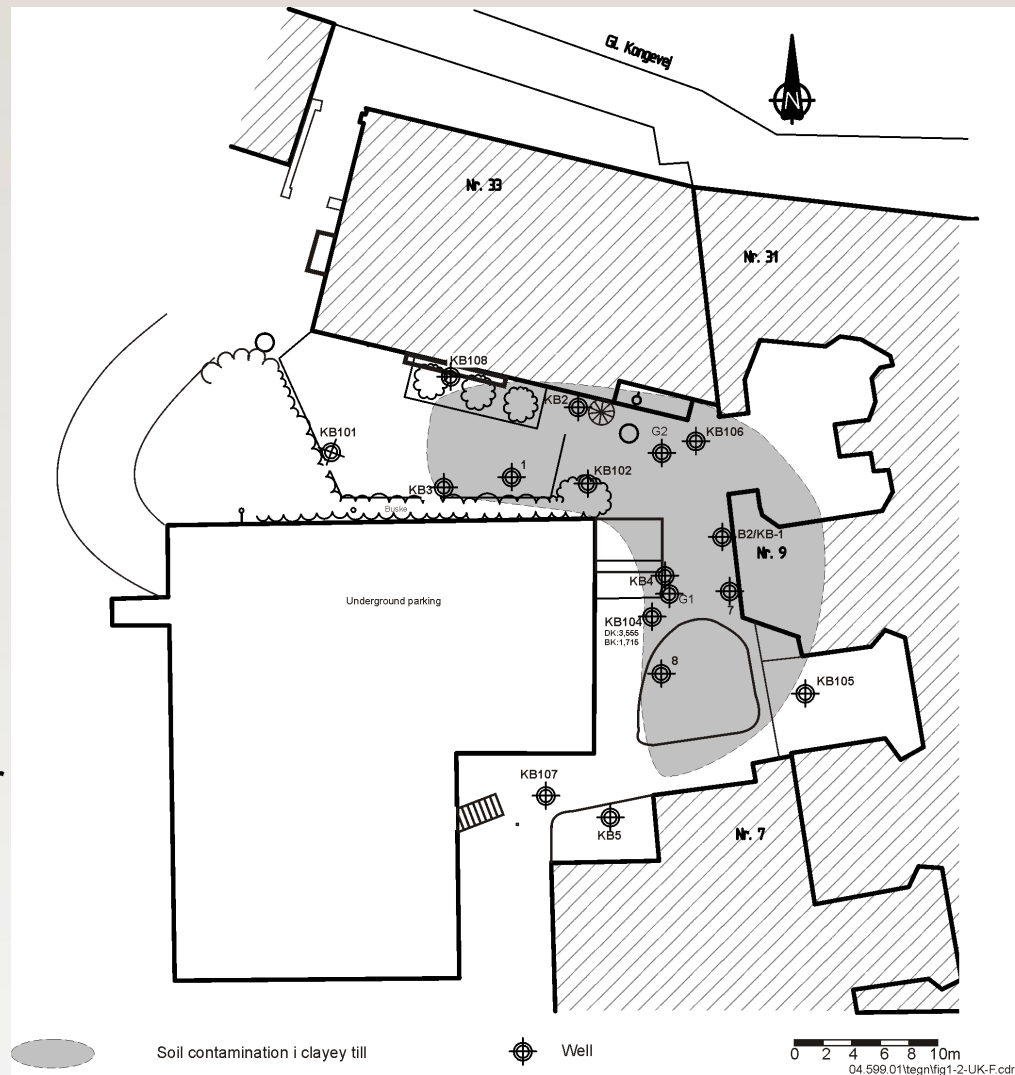


Site description: Geology & conceptual model

Meter below ground



- Remaining contamination in clayey till inaccessible for remediation
- PCE plume in the top of the limestone
- Currently low concentrations due to gw extraction at neighbor property
- Site located in catchment area of water supply



Long term cut-off or containment methods:

1. Pump & Treat vs.
2. Enhanced Reductive Dechlorination

Enhanced Reductive Dechlorination Strategy:

Active phase:

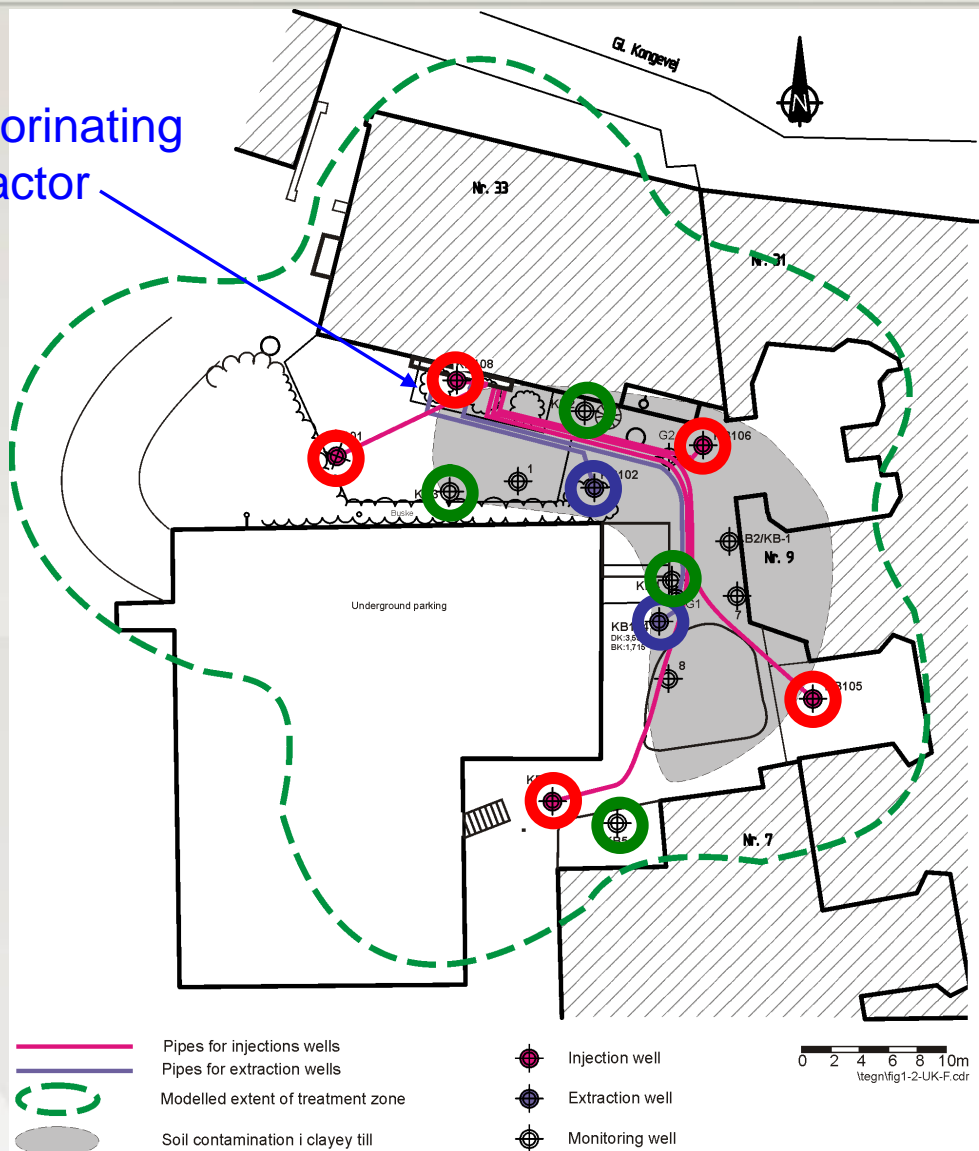
- Clean-up existing plume in limestone
- Create a horizontal bioreactive barrier in the top of the limestone

Passive phase:

- Maintenance of the bioreactive barrier through periodic substrate injections

Active phase: system layout

Dechlorinating bioreactor

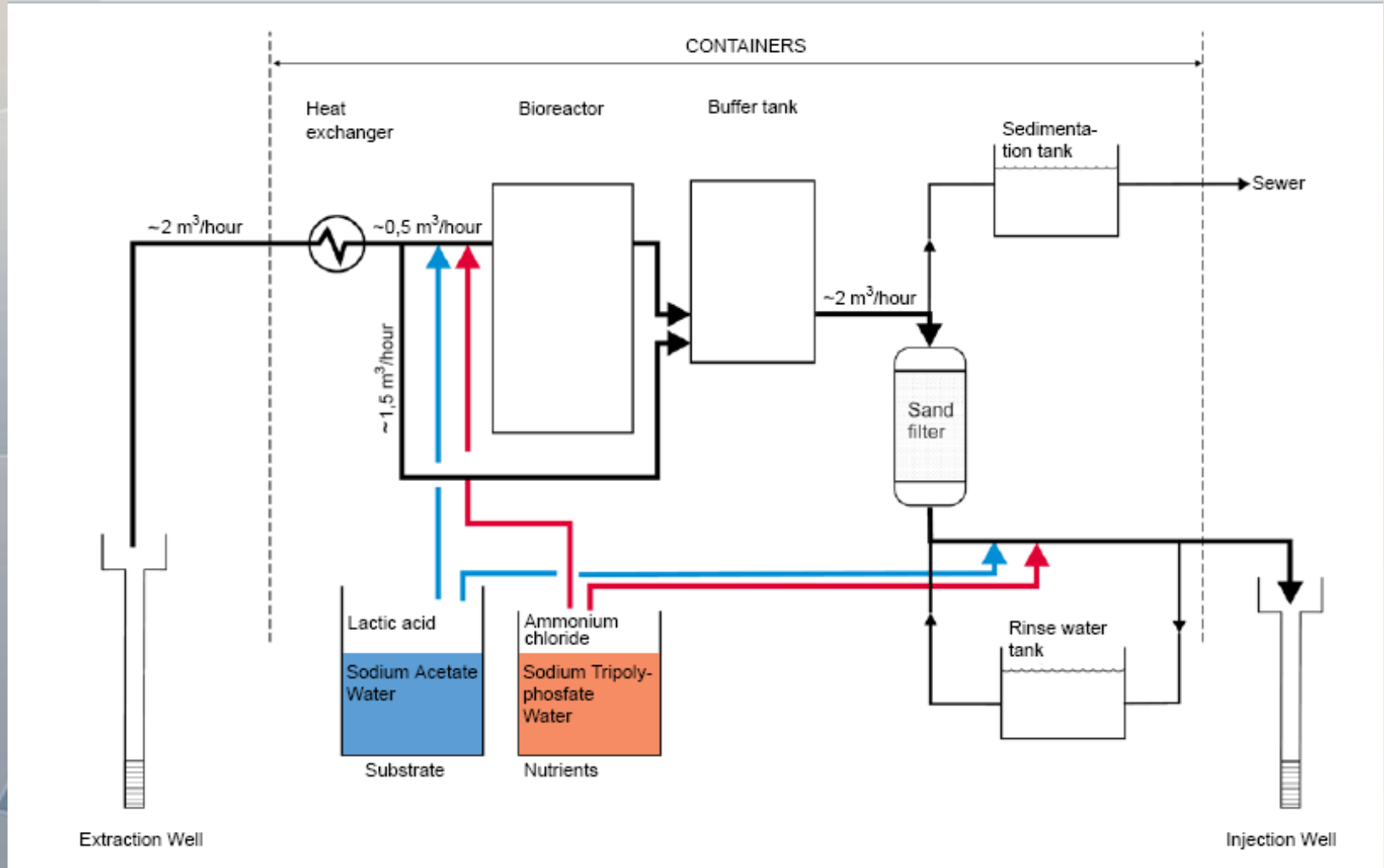


5 injection wells

2 ekstraction wells

4 monitoring wells

Active phase: Water treatment with dechlorinating bioreactor



Active phase - operation

Operation: 1 September – 20 November 2006

Substrate and nutrient dosing:

Pulswise (1/day) and separated in time

Substrate dosing Week 1-9: 100 mg TOC/L

Week 10-11: 600 mg TOC/L

Biomass: Continuous Dhc dosing from bioreactor

Criteria for terminating the active phase:

- No sulphate
- Sufficient substrate for maintenance of RD (>10 mg TOC/L)
- Sufficient number of Dehalococcoides Ethenogenes (>10⁴ Dhc/mL)
- Ongoing RD, increasing degree of dechlorination

Passive phase – maintenance of the bioreactive barrier

Substrate dosing:

2 weeks of recirculation at high substrate dosing

Monitoring

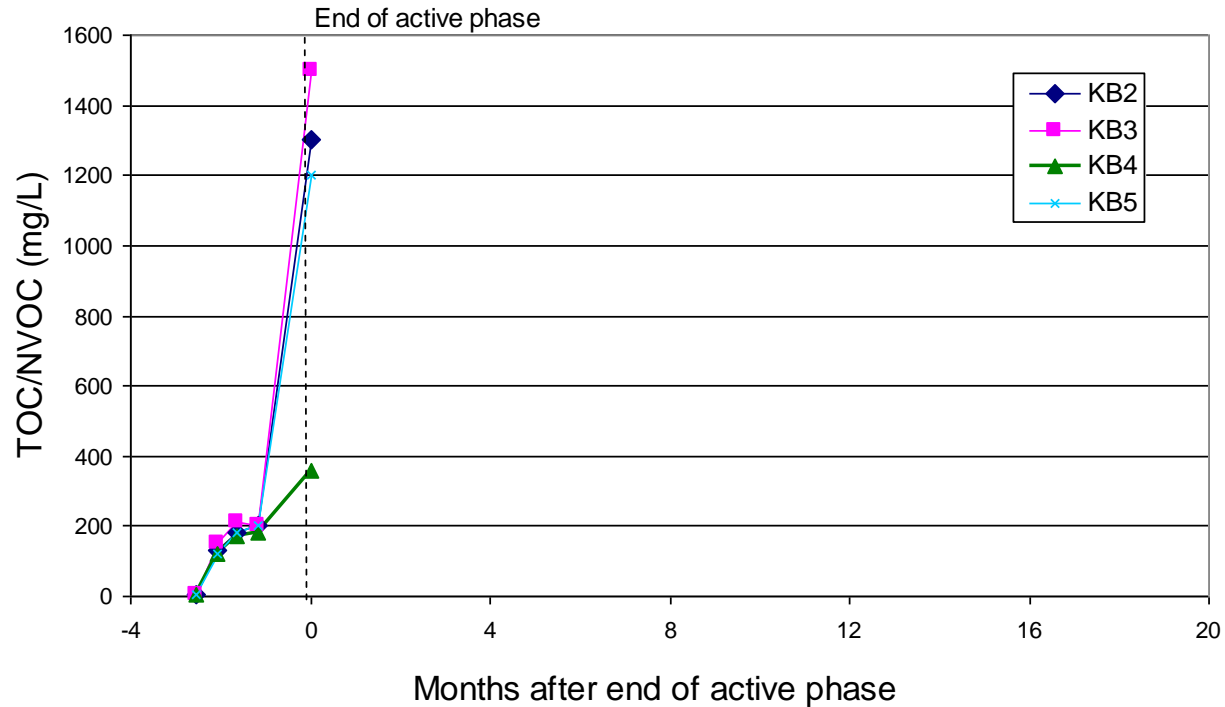
Quarterly monitoring (water sampling) during the passive phase

Frequency of substrate amendment:

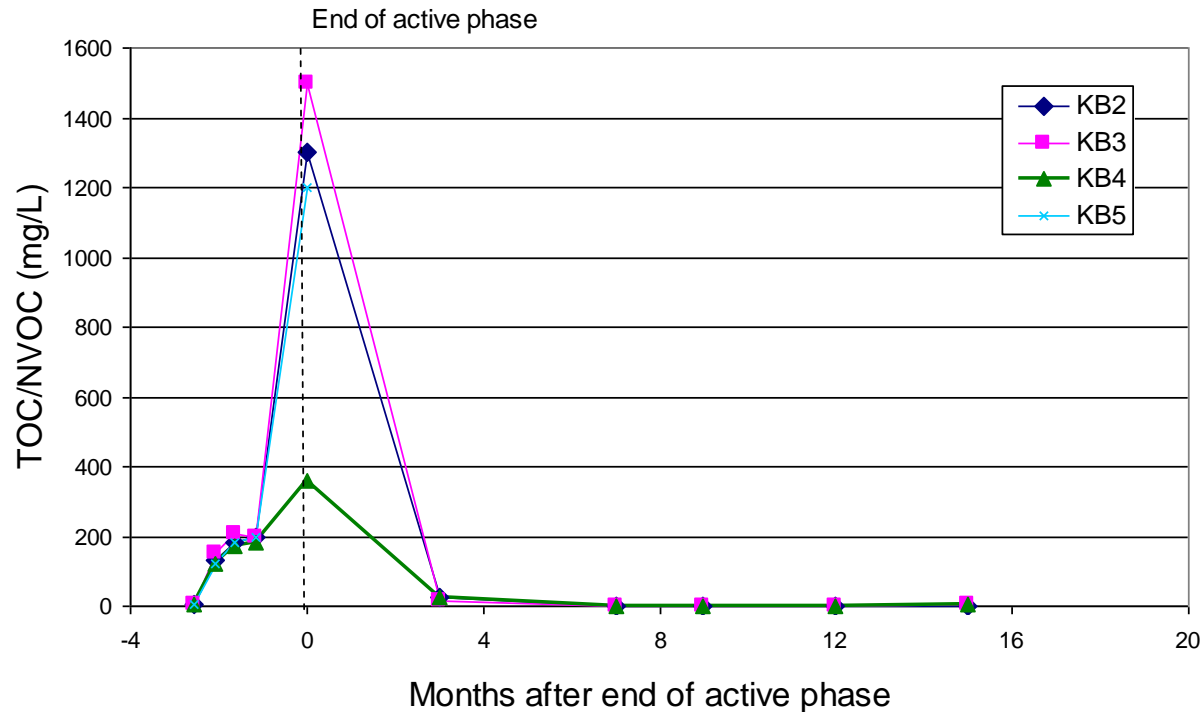
Approx. every 1-1½ years after recontamination within the treatment zone

Monitoring results will determine the exact time for the next substrate dosing

Monitoring results: Active phase - Substrate

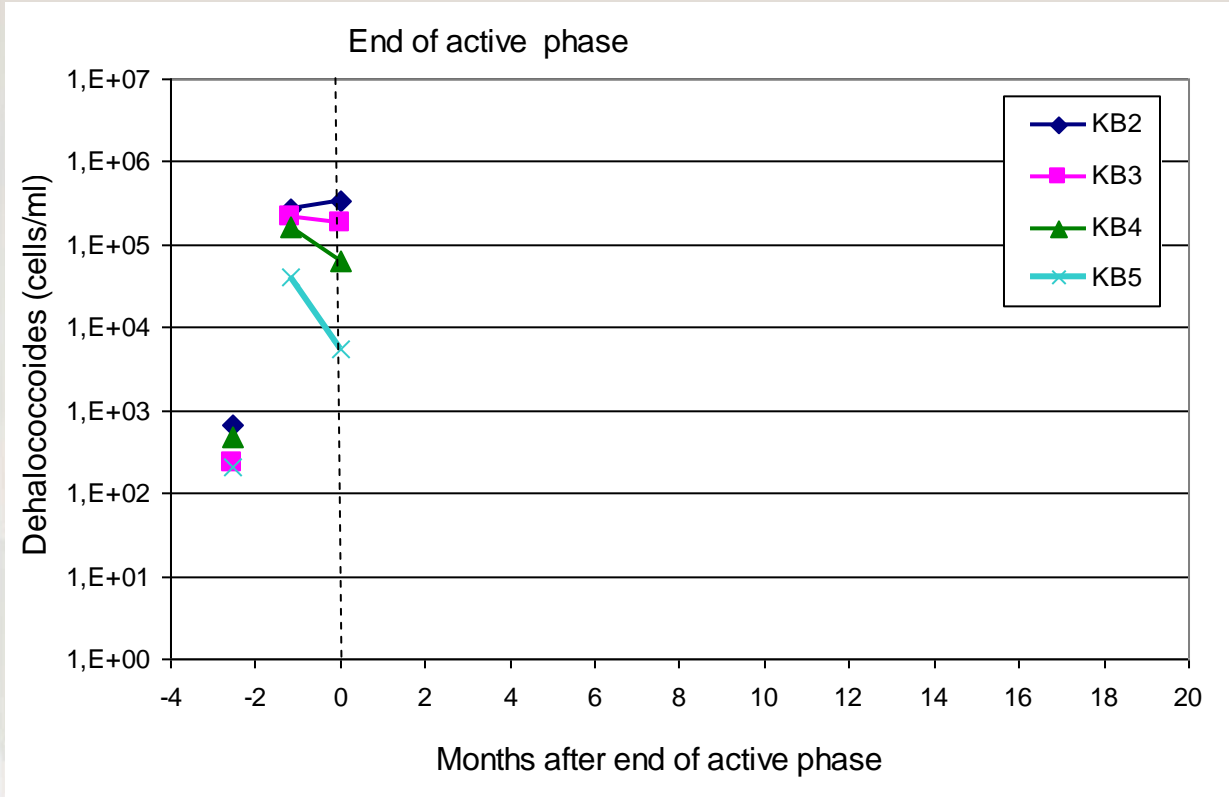


- Even distribution of substrate after 2 weeks of operation
- Rapid build-up of substrate in the treatment zone

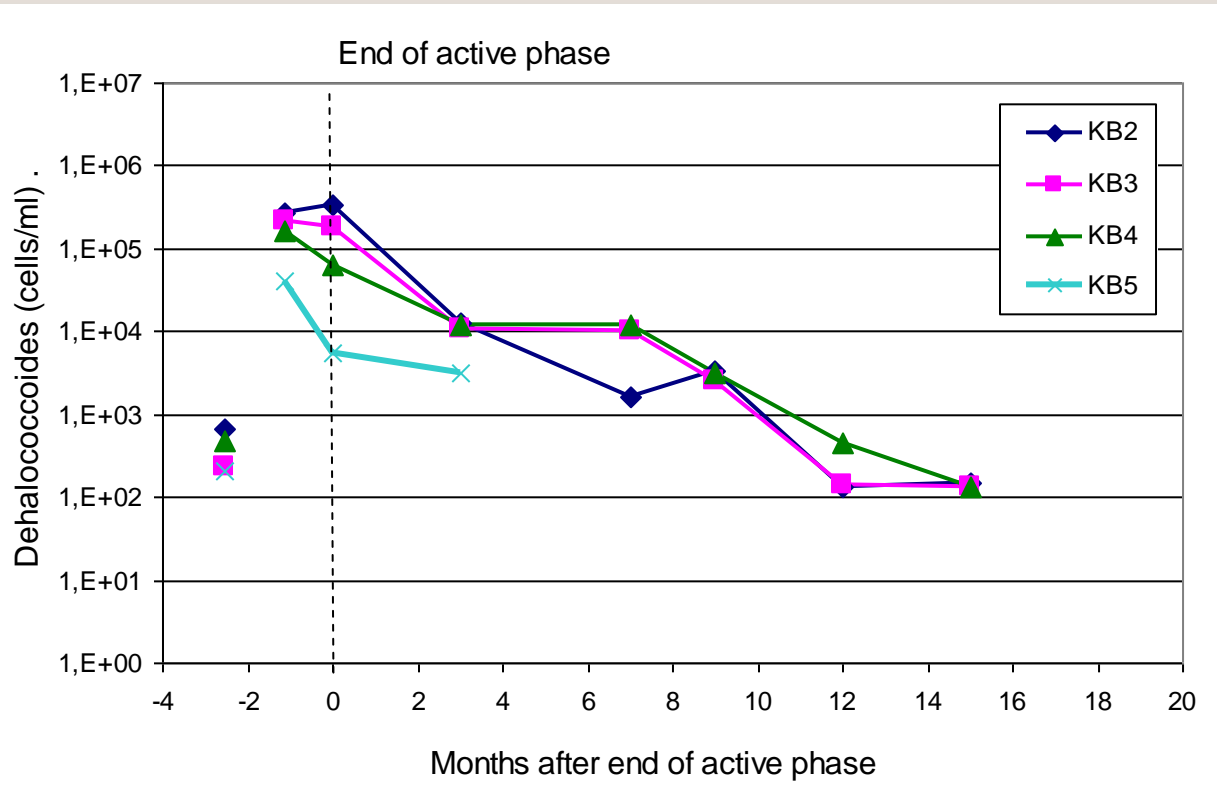


- Marked decrease to 10-25 mg TOC/L after 3 months
- < 10 mg TOC/L after 7 months
- Biodegradation? Flushing? Diffusion into matrix?

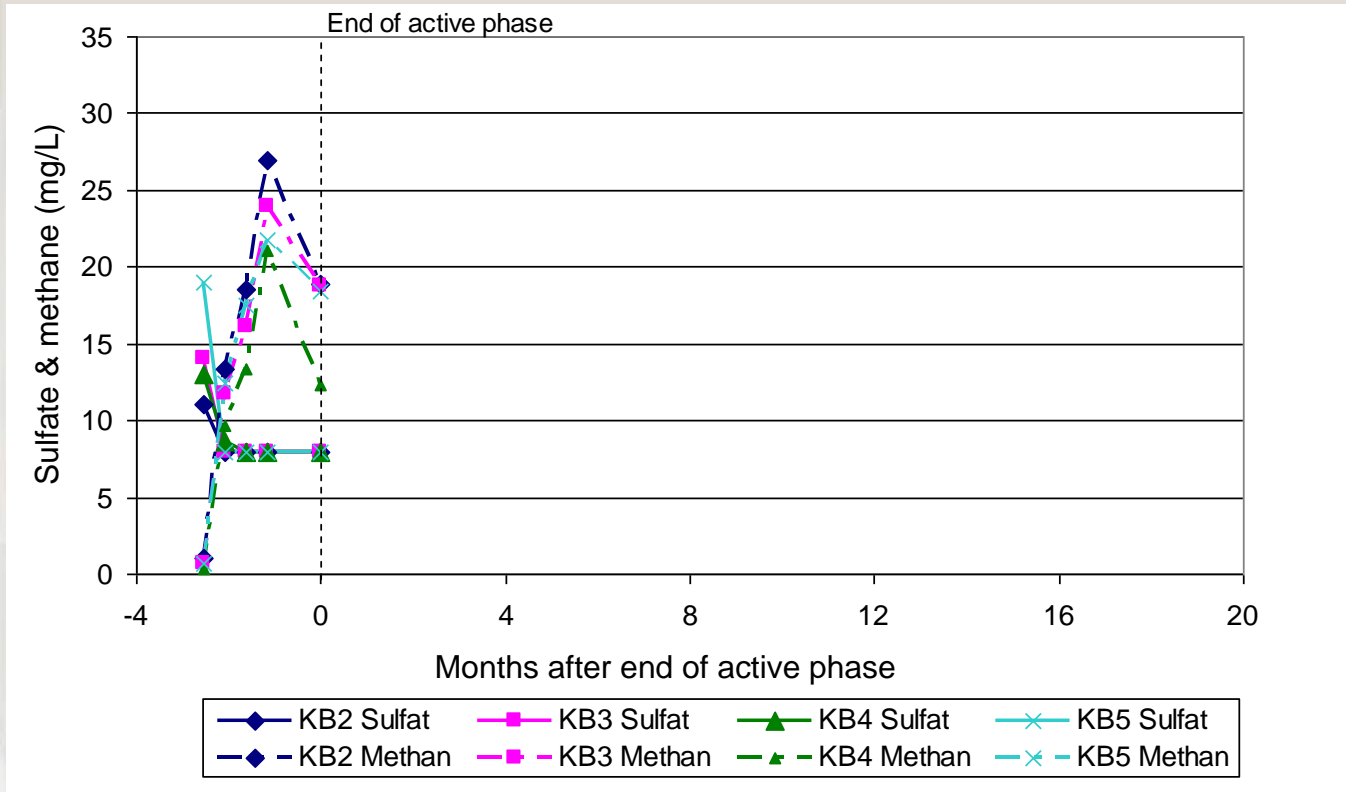
Monitoring results: Active phase - Biomass



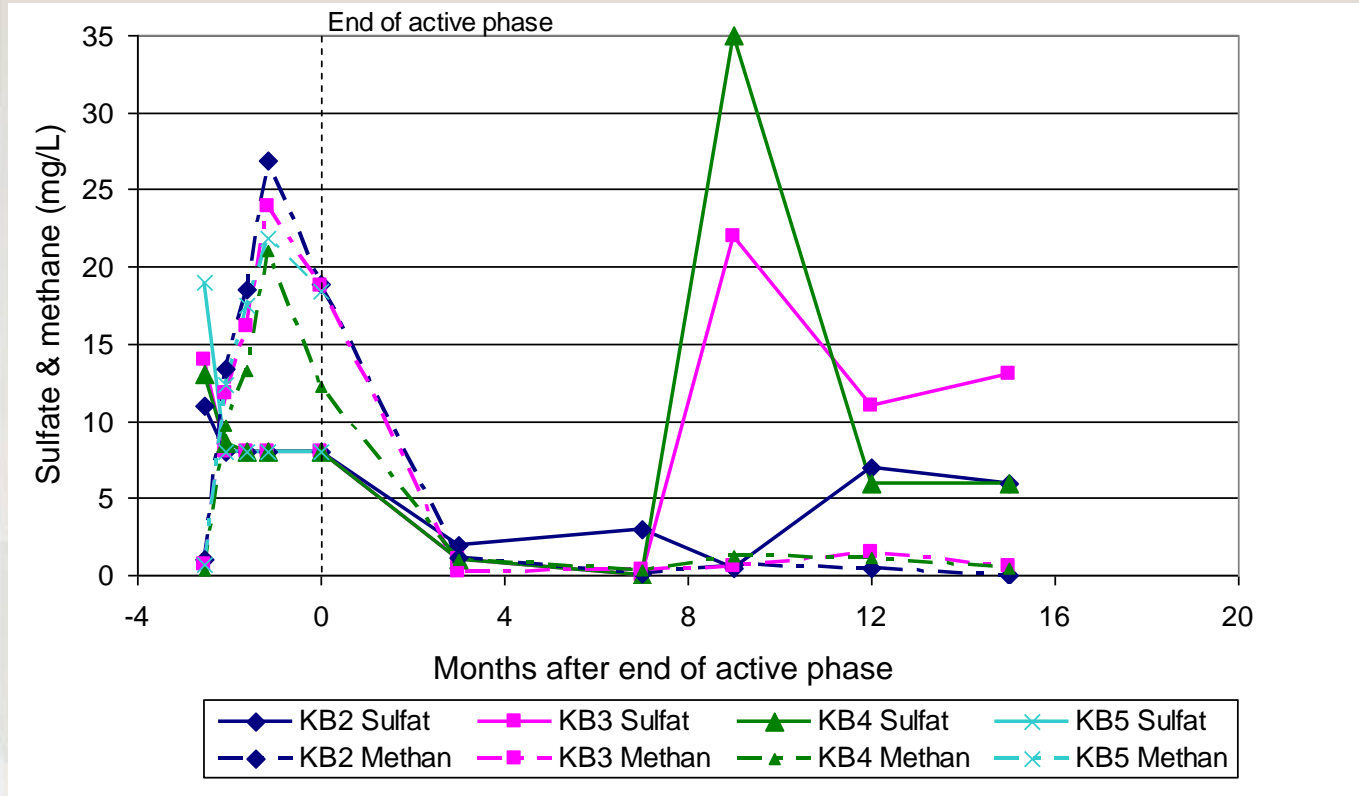
- High numbers ($3E+05$ Dhc/mL) of Dhc evenly distributed after 4-6 weeks of operation (most likely after 2 weeks)



- Decrease to 1E+04 Dhc/mL after 3 months, then stable
- Dhc back at background level after 12-15 months
- Dhc: almost all contain VC-reductase gene
- Sustained dechlorinating activity: TOC in matrix?

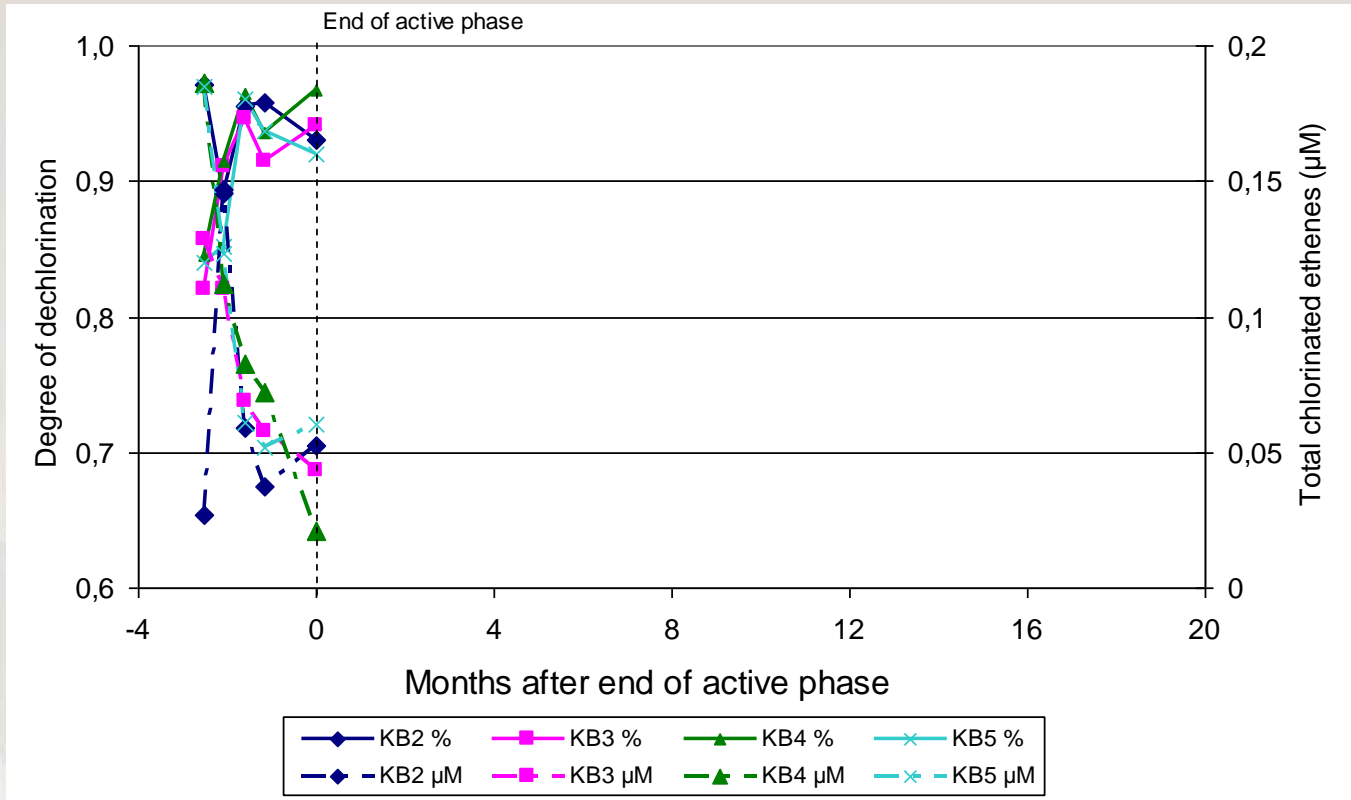


- Sulphate b.d. (8 mg/l) after 2 weeks of operation
- Methanogenesis after 2 weeks of operation
- Methane increases to \geq solubility = optimal for RD

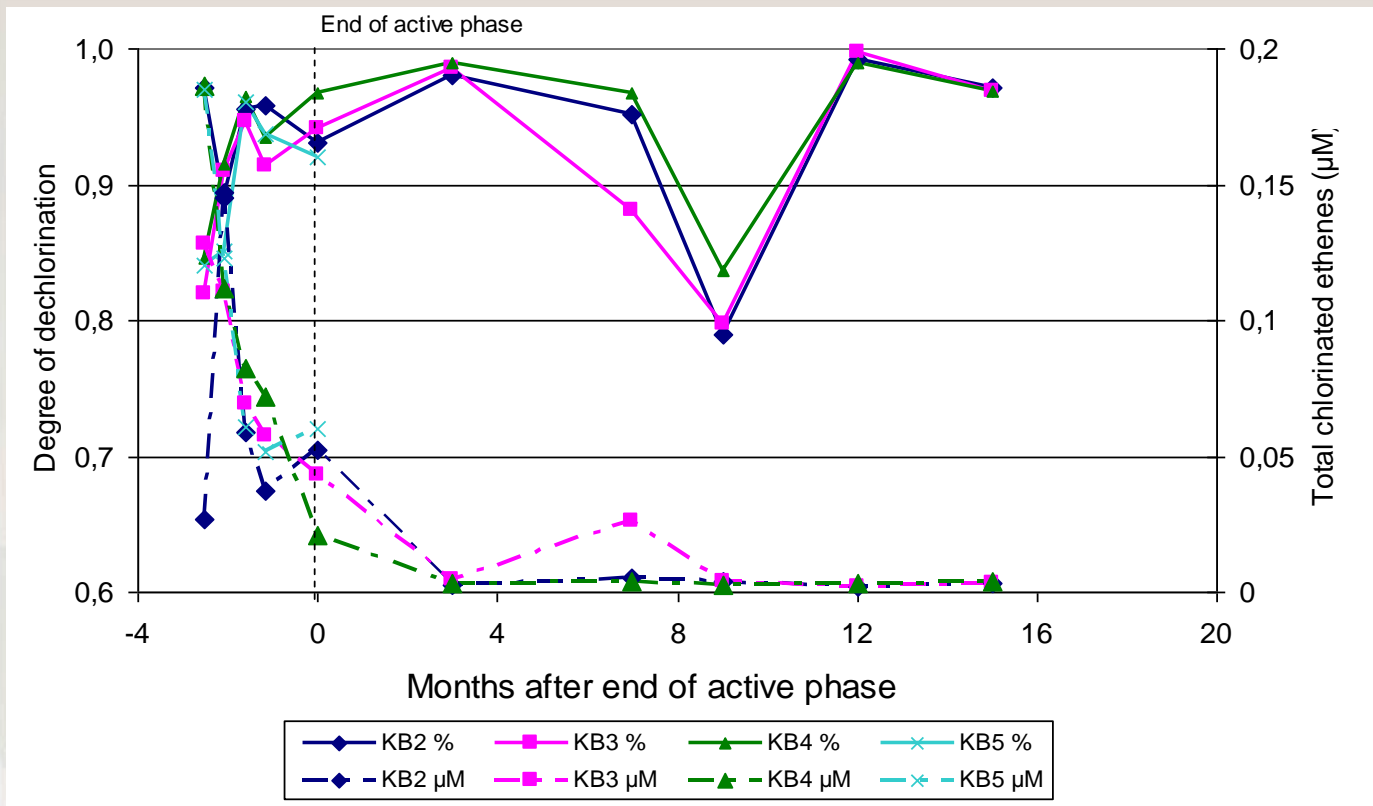


- Drop in methane after 3 months!
- No increase in sulfate 7 months after active phase
- Increase in sulfate 9-15 months: TOC gone?

Monitoring results: Active phase – Dechlorination



- Degree of dechlorination increasing (~85% to ~95%)
- Sum of VOCs decreasing (reduced to ethene)
- Increased dechlorination in the treatment zone



- Degree of dechlorination continue to increase (to ~99%)
- Sum of VOCs decreases further, to 0.15-0.26 µg/l ΣVOC and 0.05-0.12 µg/l VC (< MCL).
- Sustained dechlorination in the treatment zone in passive phase
- 9-15 mo: VOC gone: end of dechlorination (?)

Active phase

- No clogging of the infiltration wells
 - Substrate and nutrients added pulswise, separately
 - Acidic substrate mixture (~ pH 4)
- Bioreactor has continuously generated dechlorinating biomass
- Fast and efficient distribution of substrate and biomass to the aquifer
 - 2 weeks even distribution (as modelled!)
 - Bacteria: merely added or are they growing in situ?
 - Degradation in bioreactor or in the aquifer?

Passive phase

- TOC og methane decrease: Flushing?
- But: VOCl decreases, sulfate is low, Dhc stabile:
 - Sustained dechlorination 9-15 mo. after active phase
 - Bacteria are growing in the aquifer
 - Source of substrate in the aquifer: Diffusion? Desorption?
 - Dechlorination over 15 mo.: VOCl is degraded
 - Dhc stick to the limestone despite strong flushing, at least as long as substrate /chlorinated solvents are present
- Interaction between fractures and matrix
 - TOC non detect in water phase
 - Processes show TOC source 9-15 mo. after the end of the active phase

Overall

- Efficient ERD barrier achieved (cut-off-/ polishing method)
 - Very low VOCl concentrations reached:
 - 0,15-0,26 µg/l Σchlorerede ethenes
 - 0,05-0,12 µg/l vinylchlorid
- Must be operated for years! (same time frame as for pump & treat)
 - but: - in situ destruction of VOCl
- no on site treatment
- less maintenance

Questions?