Milieu calcaire fracturé – Défi dans l'application de la BAND (Bio-Atténuation Naturelle Dynamisée)

Fractured limestone – challenges in applying In-Situ Bioremediation

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Intersol 2009 – Paris sud – 24 March 2009

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What are the main challenges in fractured limestone?

Dual porous media: fractures and matrix

- Unpredictable flow (overall flow direction ≠ where groundwater flows)
  - Plume delineation, vertical spreading – fracture flow
  - Zones of major inflow
  - How do we control distribution of amendments?
- Interactions between fractures and matrix - sorption/diffusion
  - What do we measure in water samples?
  - How can we estimate what is in the matrix?
  - And the effects and longevity of matrix contaminants/EAs?
- Investigations and remediation
- Is hydraulic control (Pump&Treat) really the only remedial option?

Bio-remediation strategy

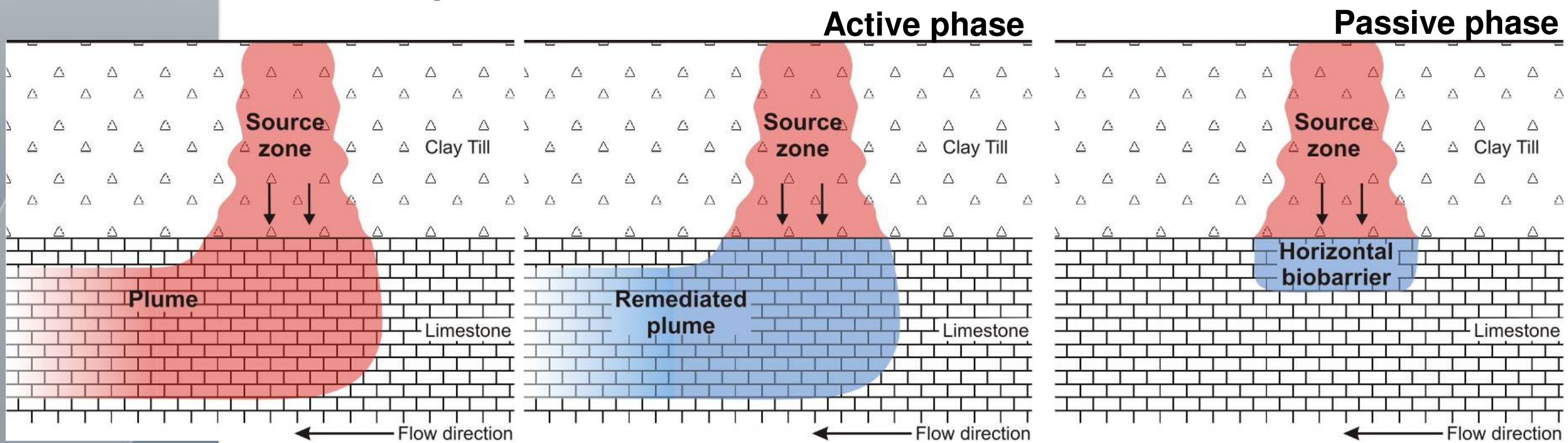
ERD: Enhanced Reductive Dechlorination

Remediation and cut-off of PCE/TCE plume

Long-term remediation due to poorly accessible source zone

Plume in fractured limestone

ERD concept:

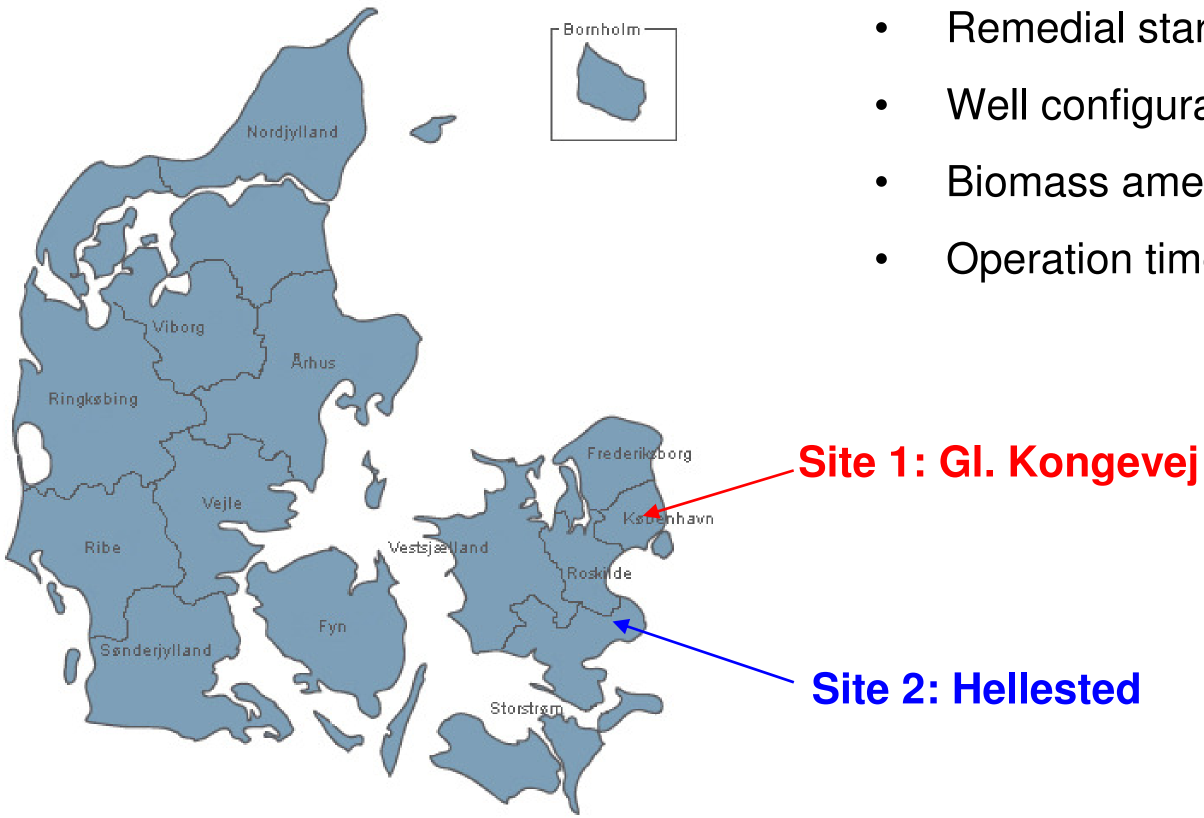


ERD: viable and more cost-effective than Pump&Treat

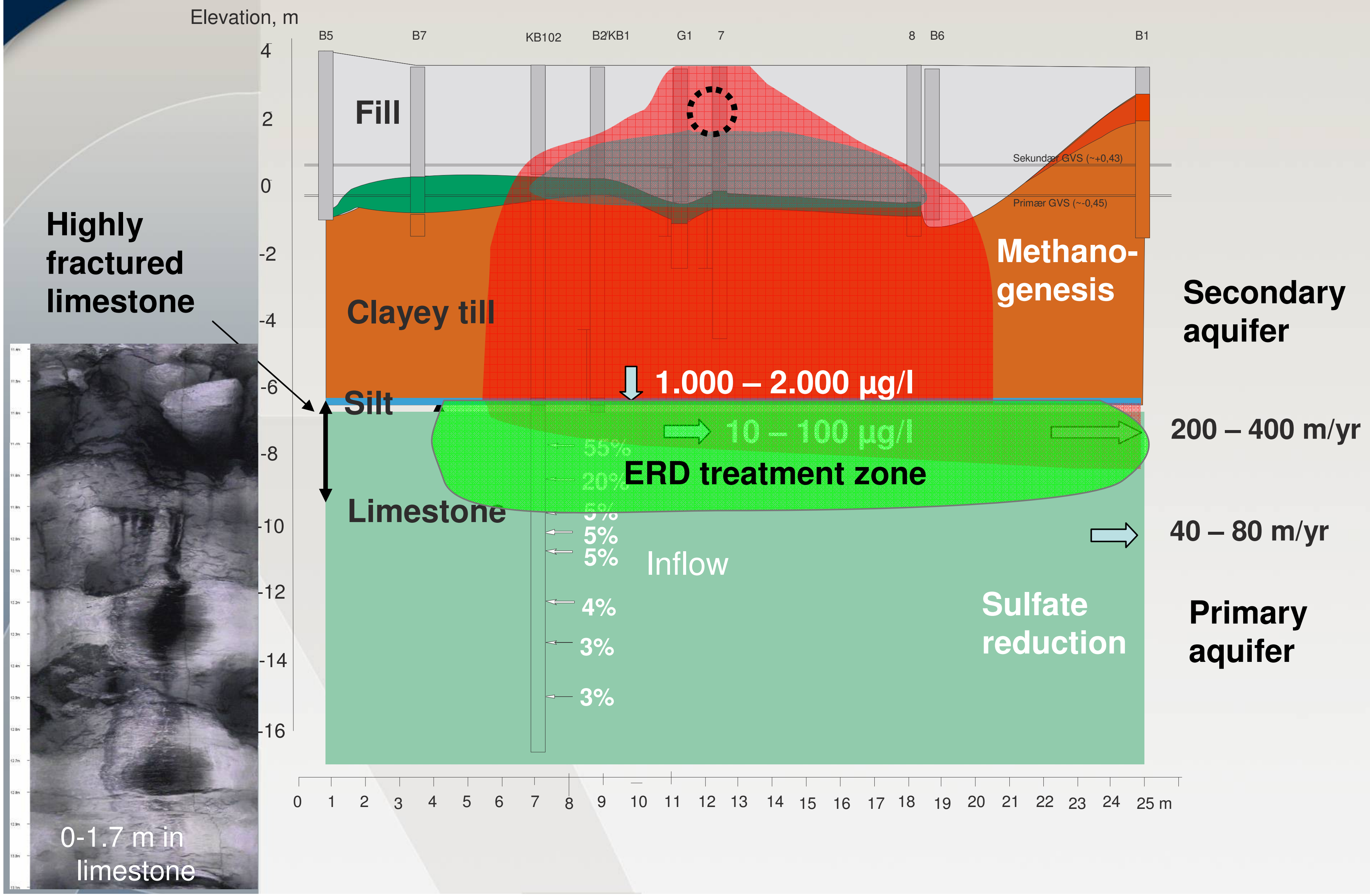
Two sites in Denmark

2 sites - differences:

- Type of limestone
- Plume volume
- Remedial starting point
- Well configuration
- Biomass amendment
- Operation time



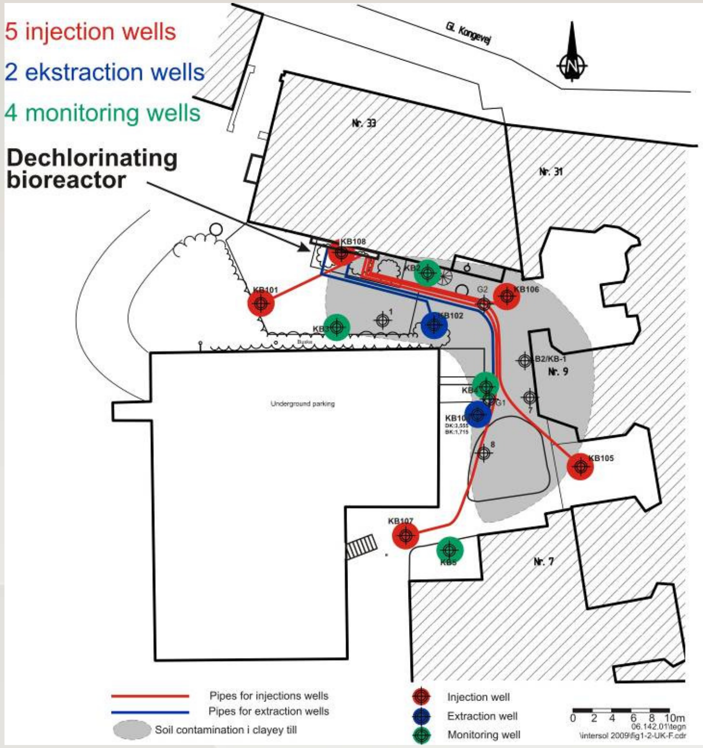
Site 1: Gl. Kongevej: Geology & conceptual model



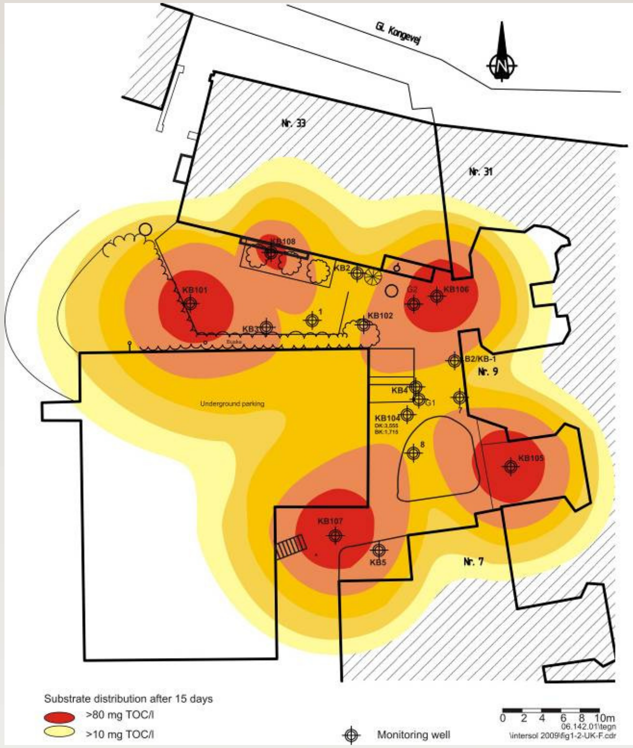
Gl. Kongevej. Site plan

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

Gl. Kongevej. Active phase: system layout



Well configuration



Modelled substrate distribution

Substrate: Na-acetate + lactic acid

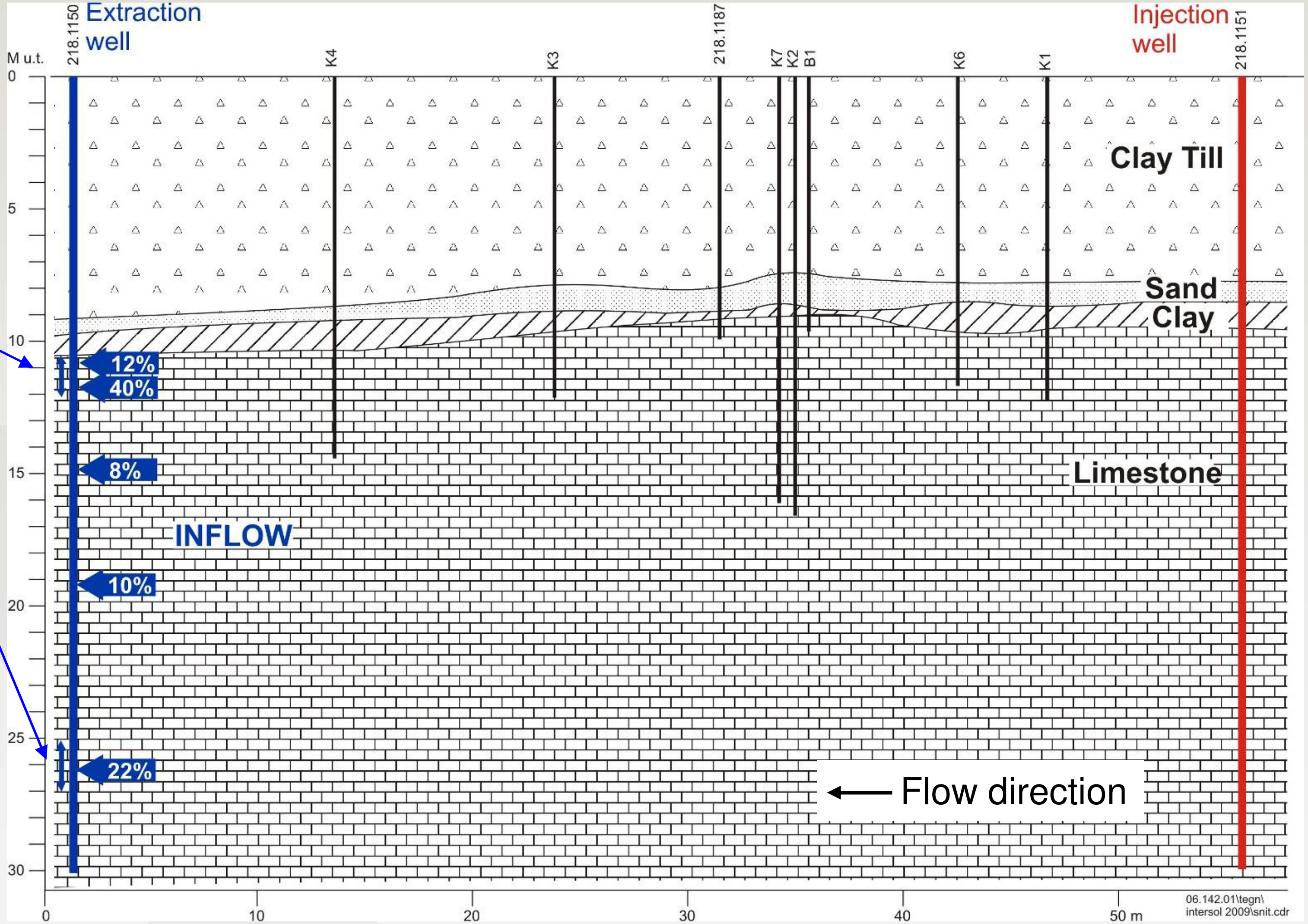
Operation of active phase: September-November 2006

Operation of passive phase: November 2006

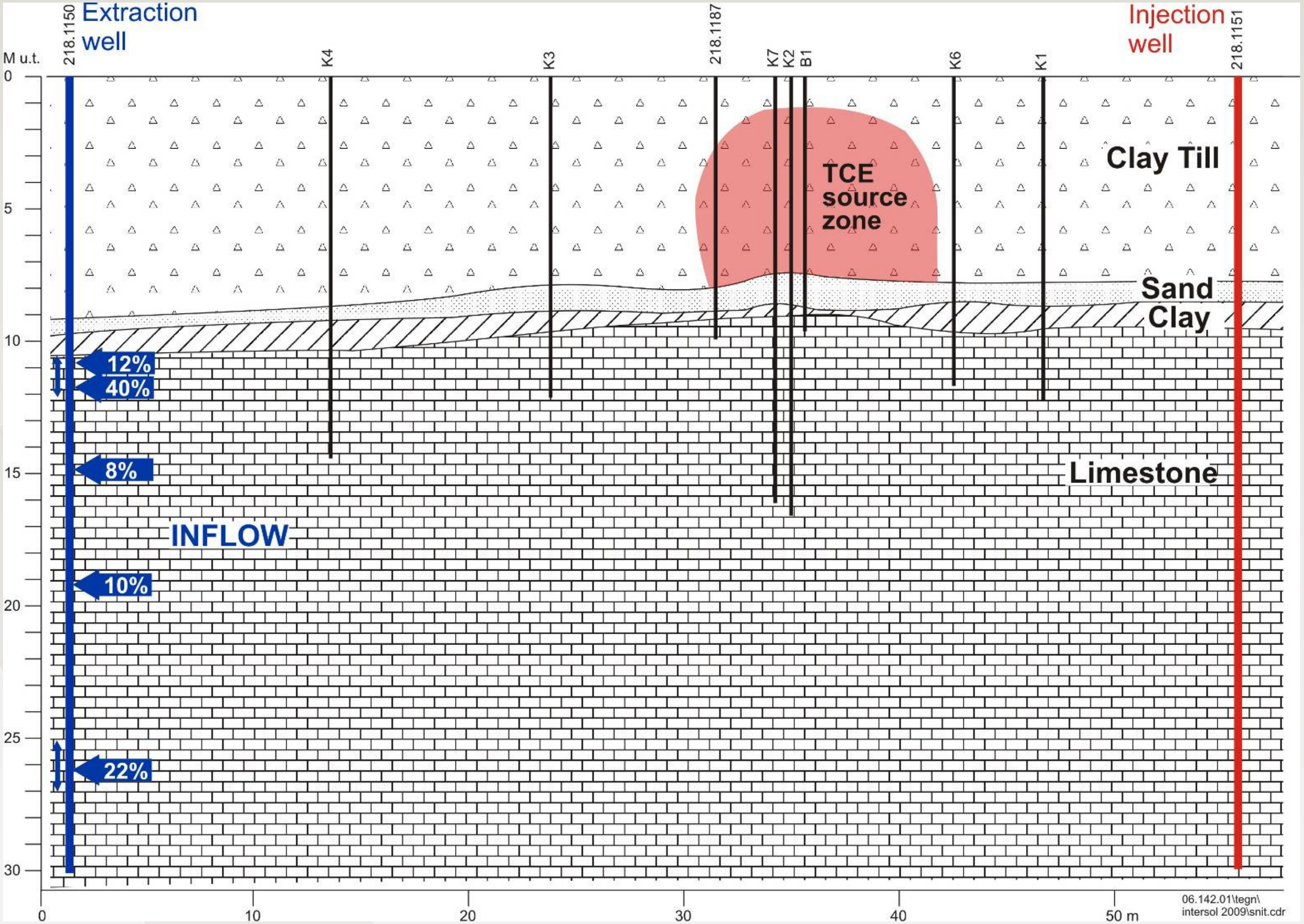
Monitoring: December 2006 – February 2008

Site 2: Hellested. Geology and conceptual model

Major inflow zones



Site 2: Hellested. Geology and conceptual model

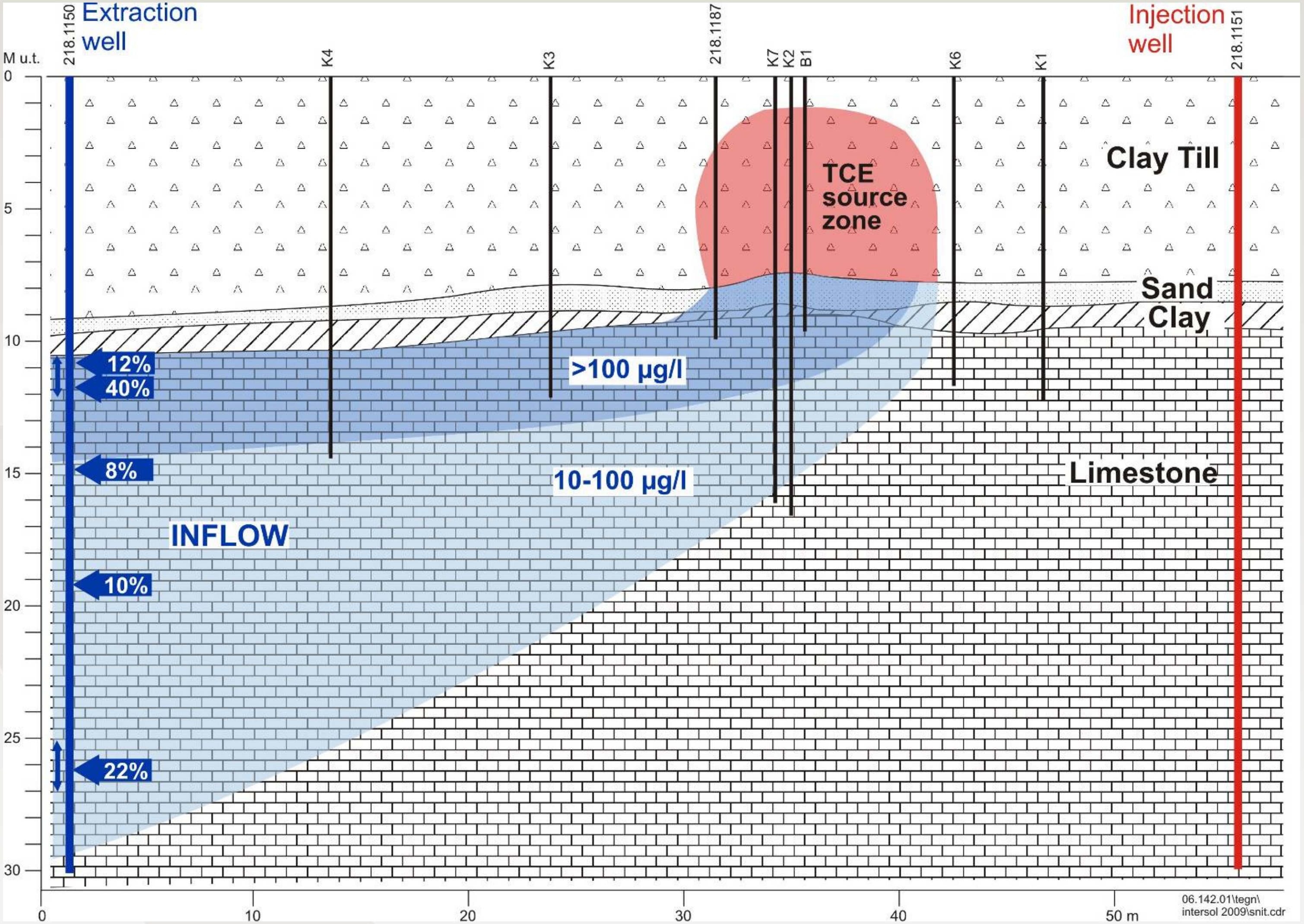


Site 2: Hellested. Geology and conceptual model

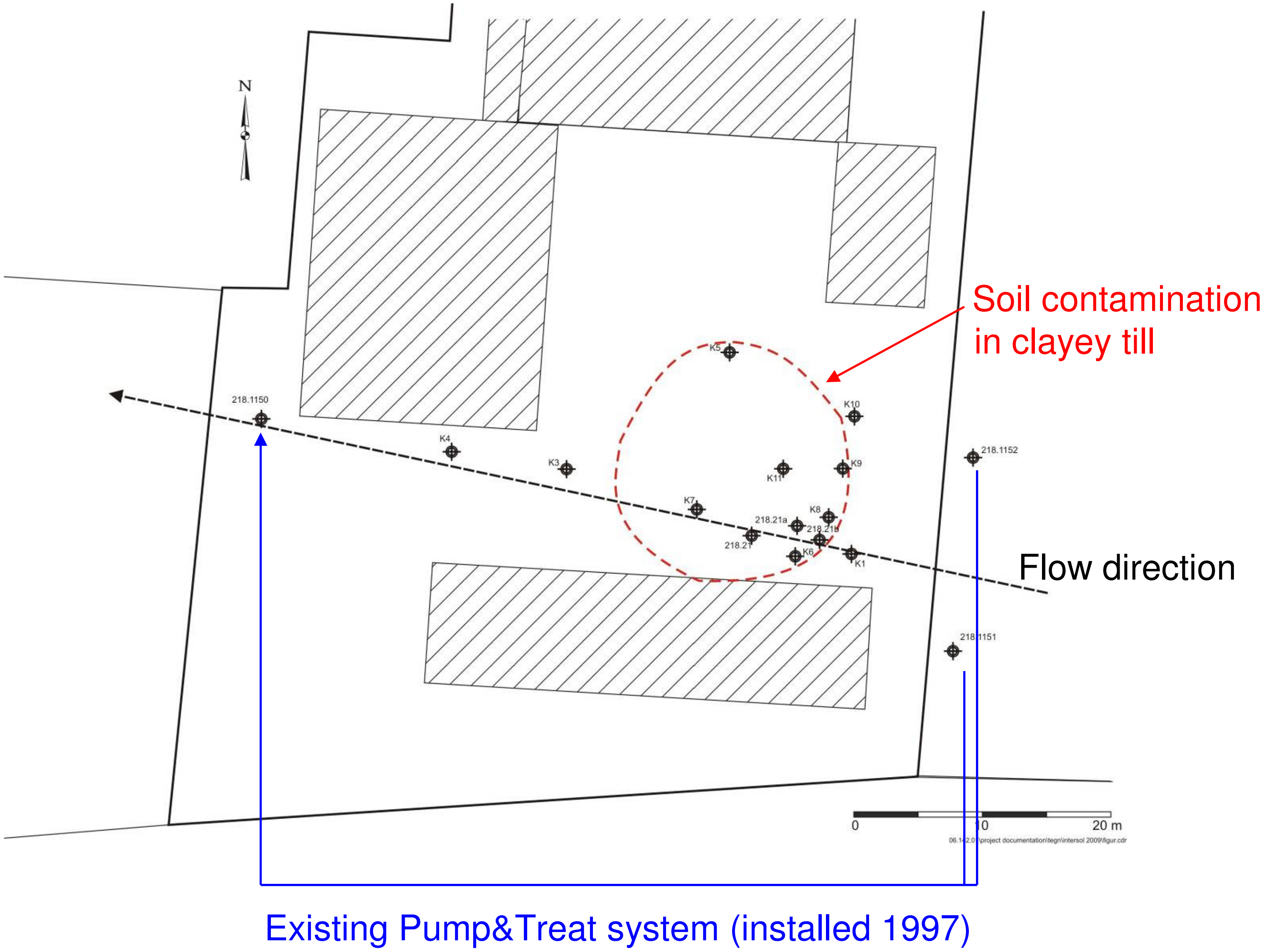
Tracer test:
Fluorescein in K7

58% mass in extr.well in 60 days

→ P&T: deep TCE spreading



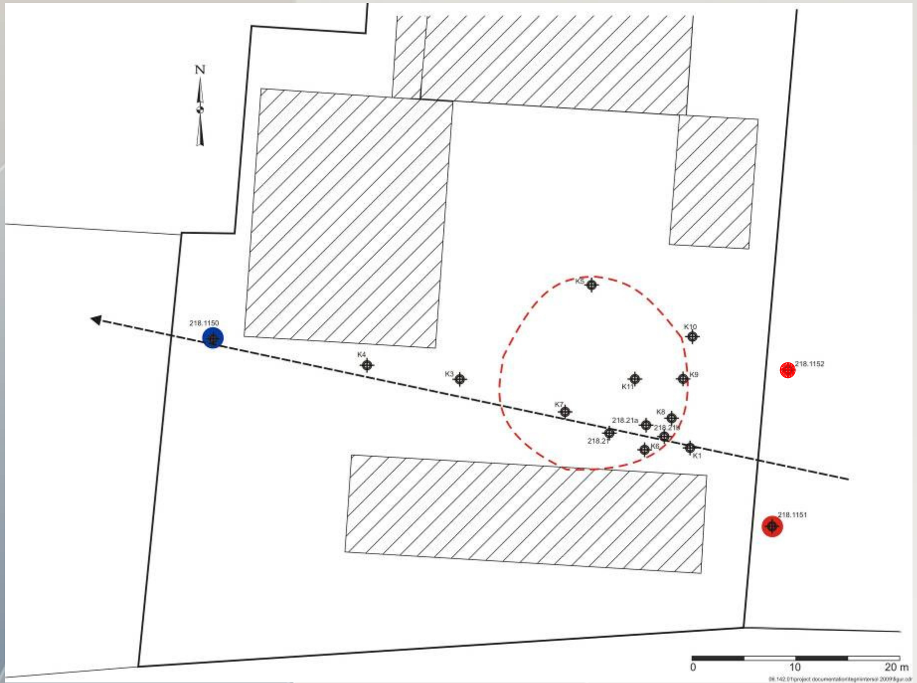
Hellested. Site plan



Hellested. Active phase: System layout

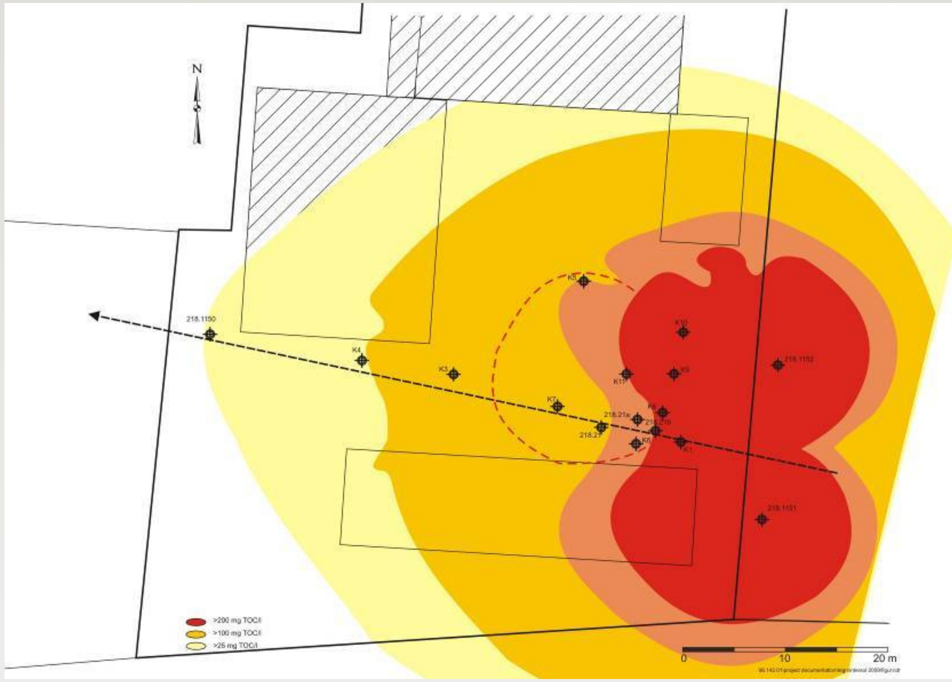
ERD design: Take into account existing P&T system

1) re-use of wells 2) plume spreading



Well configuration

Direct biomass injection



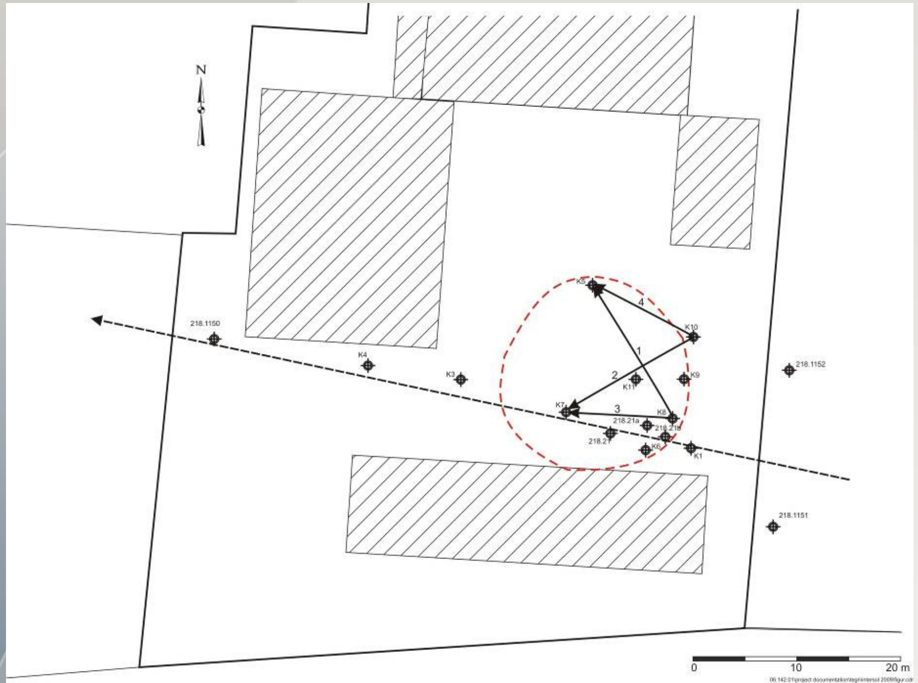
Modelled substrate distribution

Substrate: Na-lactate

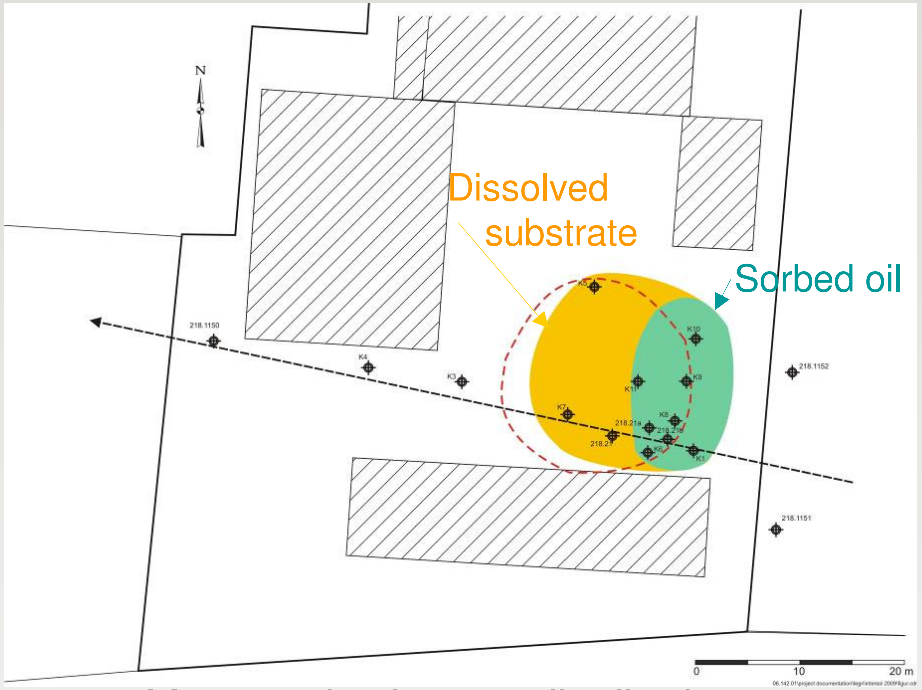
Operation of active phase: June – November 2008

Hellested. Passive phase: System layout

Different well configuration for passive phase – smaller aquifer volume needed to be maintained as bioreactive



Well configuration: 4 loops



Measured substrate distribution

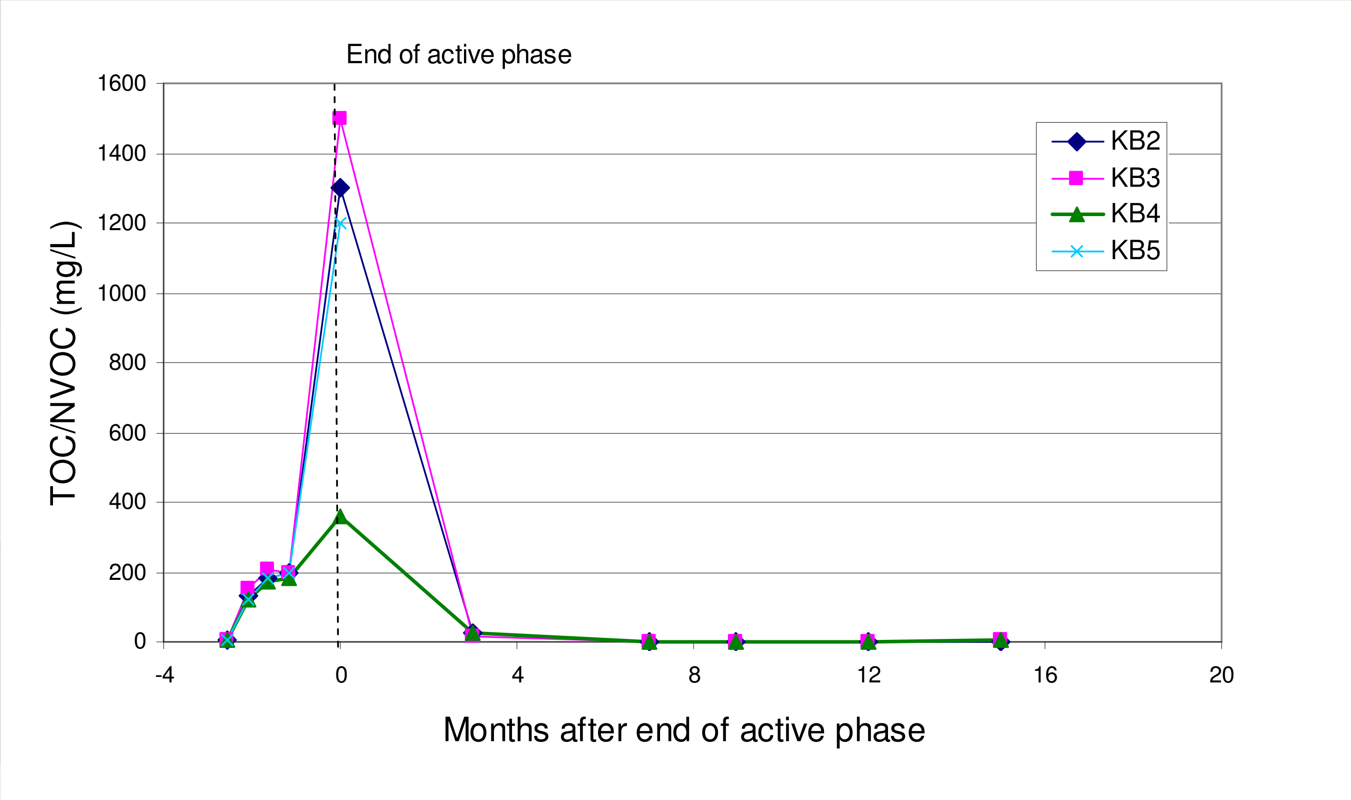
Substrate: EOS (emulsified veg.oil)

Pumping test, passive phase system: November 2007

Operation of passive phase: November – December 2008

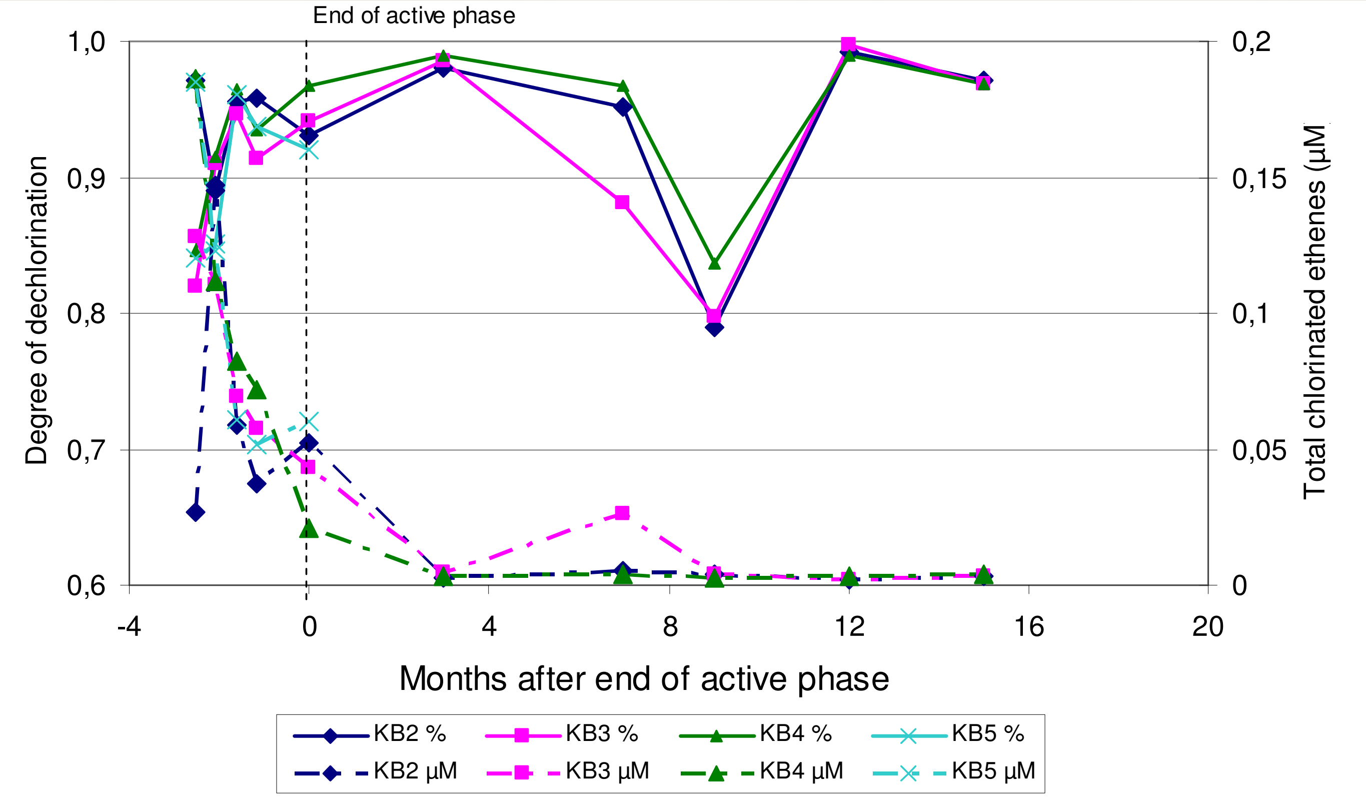
Monitoring: December 2008 - *ongoing*

Gl. Kongevej Monitoring results: Substrate



- Uniform distribution after 2 weeks of recirculation
- Marked decrease to 10-25 mg TOC/L after 3 mo. of passive phase
- < 10 mg TOC/L after 7 months
- Biodegradation? Flushing? Diffusion into matrix?

Gl. Kongevej Monitoring results: Dechlorination



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

Gl. Kongevej: Summary

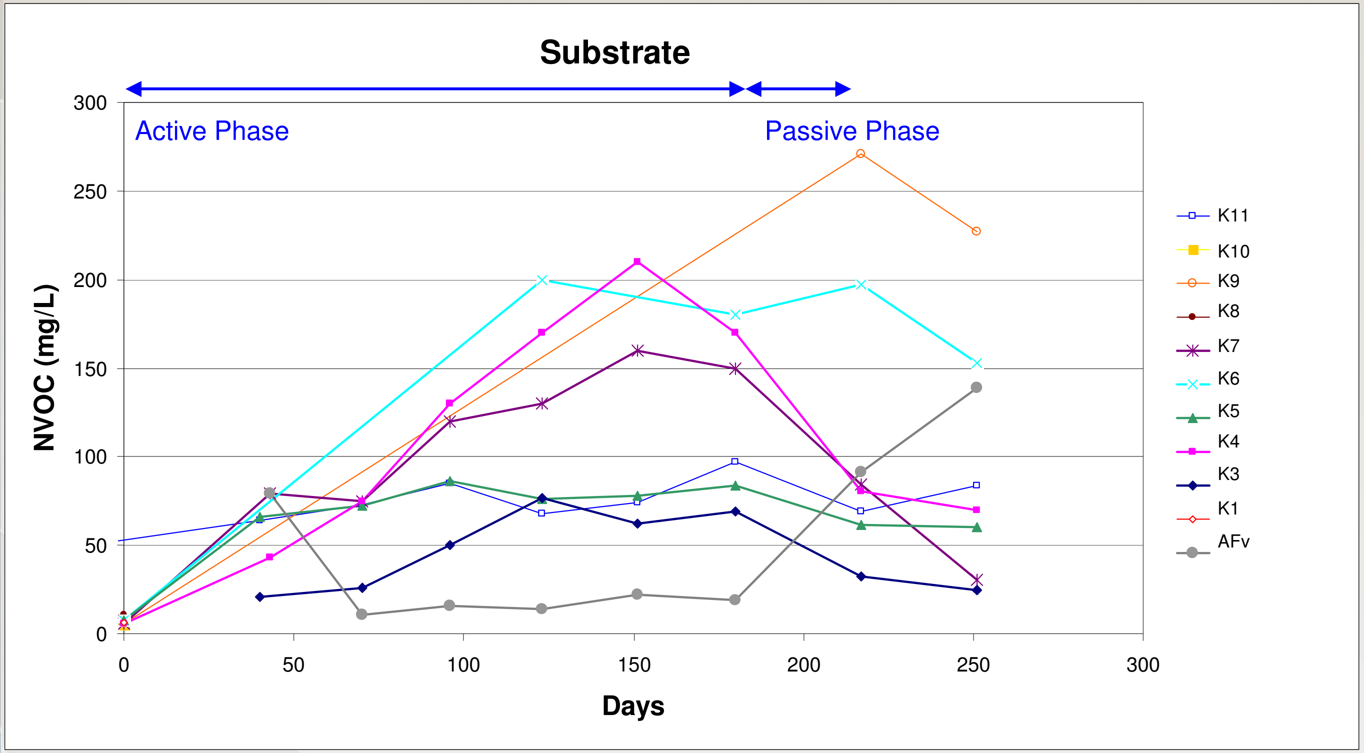
Active phase

- Fast response in all wells wrt: substrate, Dhc, dechlorination
- Redox conditions initially reduced

After active phase

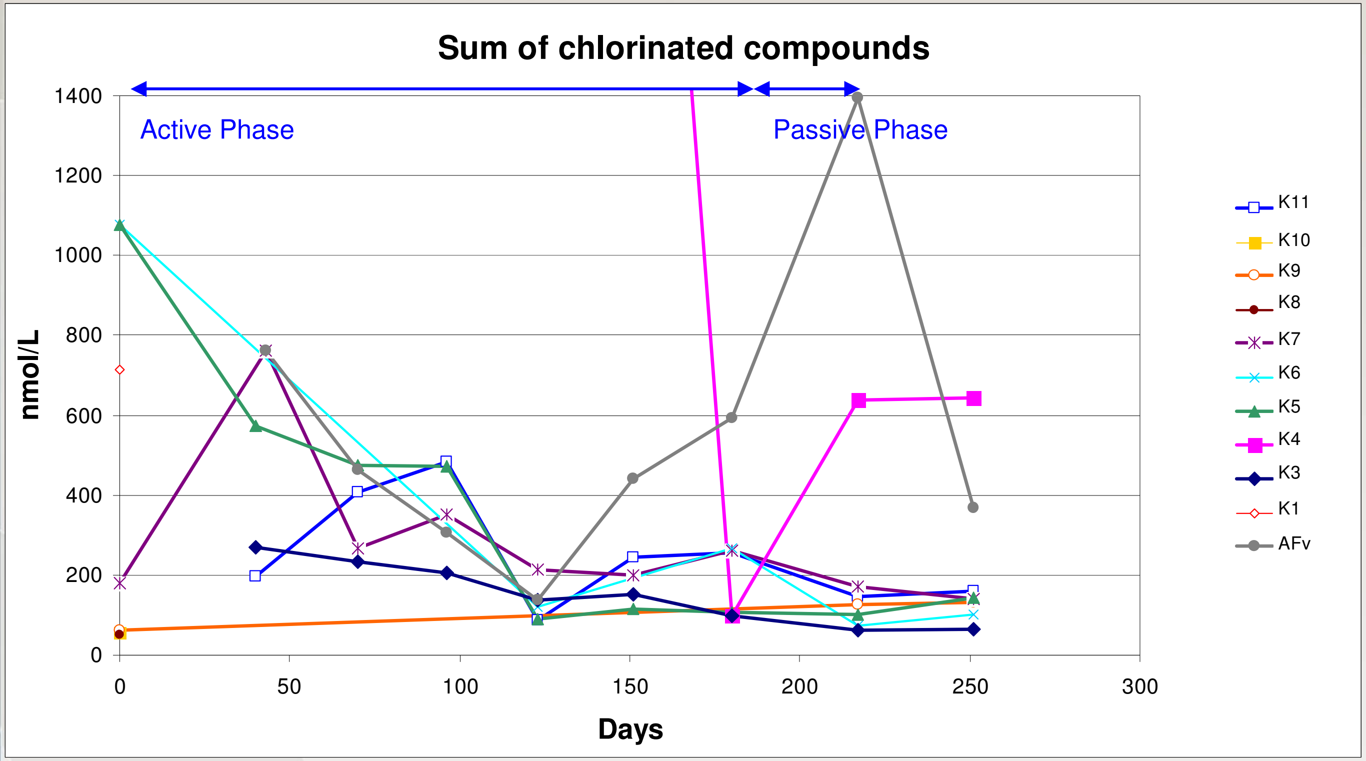
- Substrate and methane drop rapidly
- Sustained levels of Dhc and sulphate
- Sustained dechlorination 12-15 mo after active phase
- Substrate diffusion out of matrix – present, but not measurable in water samples
- Significant interactions between matrix and fractures
- Dhc are not being flushed out of the system
- CVOC concentrations <MCLs reached

Hellested Monitoring results: Substrate



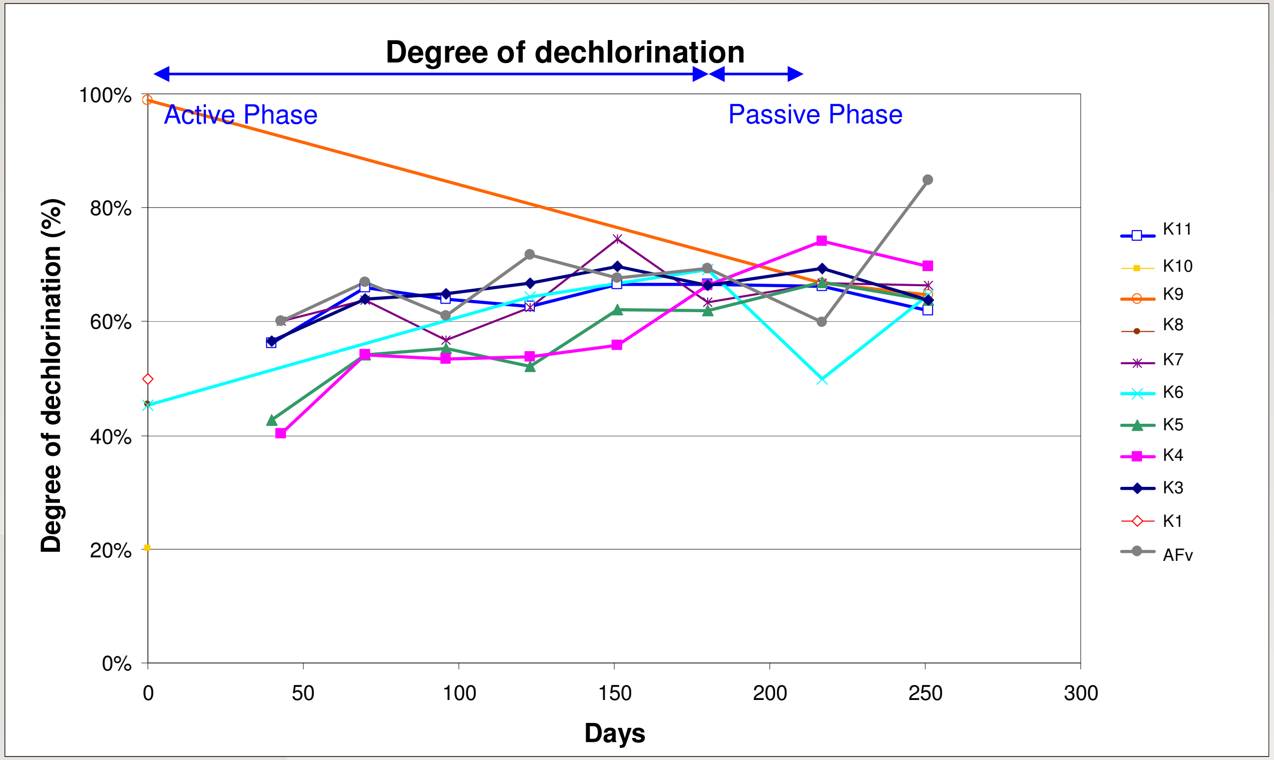
- Target NVOC (10 mg/l) reached after <60 days
- Slower reaction time than Gl. Kongevej – well configuration & treated volume
- High initial NVOC in K11 due to pumping test (Nov 2007)
- All wells are influenced by substrate amendment

Hellested Monitoring results: Dechlorination (1/2)



- Decreasing CVOC concentrations
- Start: Max 8.200 nM, now max 180 nM (~43 µg/l)
- No ethene produced yet
- Slower reaction time than Gl. Kongevej – biomass amendment, interactions fractures/matrix

Hellested Monitoring results: Dechlorination (2/2)



- Increasing degree of dechlorination
- Start: TCE only – Now: cDCE and VC only
- But: no ethene formation yet
- Reductive dechlorination is on-going
- Continued monitoring: when will complete dechlorination occur

Hellested: Summary

Hellested monitoring data: more scattered than Gl. Kongevej:

- Shorter monitoring period so far
- Limestone matrix is denser and less fractured
- 2 different pumping systems have been applied
- Pumping test w/ substrate injection performed 7 mo. prior to active phase
- Initial TCE plume larger and more complex
- Hydrogeology more complex
- Existing pumping system: slower response than ”donut configuration”
- Higher initial sulphate concentrations in matrix

EOS longevity:

- Elevated substrate concentrations 7 mo. after pumping test
- Reduced permeability in treated aquifer volume 1 yr. After pumping test

Conclusions and lessons learned (1/2)

Fractured limestone aquifers:

- Complex systems
- Hydraulic differences between types of limestone
- Possible to overcome challenges wrt distribution perpendicular to dominating fracture orientation
- Even distribution through alternating pumping strategy
- Choice of well configuration important
- Significant interactions between fractures and matrix
  - What we see is (not) what we get?
  - How do we predict interactive processes and derived effect?
  - – **Further research needed**!

Conclusions and lessons learned (2/2)

ERD in fractured limestone aquifers:

- ERD as polishing method – low CVOC concentrations reached
- Sustained dechlorination 12-15 months after amendments
- Choice of well configuration important
- No clogging of wells with soluble donor
- Reduced permeability due to EOS sorption
- ERD viable and cost-effective alternative to Pump&Treat
  - Both must be operated for years (source longevity)
  - ERD: In situ destruction of CVOCs
  - ERD: No on site treatment
  - ERD: Less maintenance

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Questions?