Field Demonstration of Biostimulation and Bioaugmentation for Remediation of Chlorinated Solvents in a Sand Aquifer

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presentation outline

1. Overview of reductive dechlorination
2. Project objectives
3. Description of demonstration site
4. Pre-design tests
   - Bench treatability tests
   - modeling
5. Pilot test design and execution
6. Results
7. Conclusions

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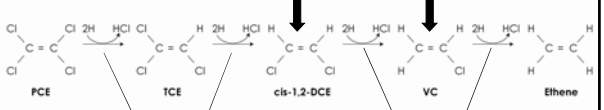
microbiology of reductive dechlorination

Can accumulate if requisite bacteria are absent



Dehalobacter
Dehalospirillum
Desulfitobacterium
Desulfuromonas
Dehalococcoides

some strains of *Dehalococcoides (Dhc)*

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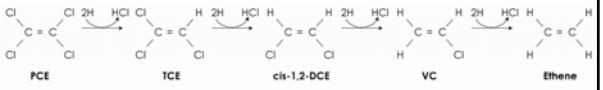
stimulated reductive dechlorination



- stimulated by injection of
  - fermentable organic compounds (electron donors), to produce dissolved hydrogen gas
  - example donors:
    - organic acids
    - alcohols
    - edible oils

  } biostimulation

  - *Dehalococcoides* cultures (e.g., KB-1®)

  } bioaugmentation

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project objective

Objective

Evaluate performance of biostimulation and bioaugmentation as a remediation technology for chloroethenes – at a *Scandinavian* site

Performance Measures

- 7-month performance period
- effective distribution of electron donor; establishment of anaerobic conditions
- ethene generation
- growth of *Dehalococcoides*

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test site: Rugårdsvej 234, Odense, Denmark

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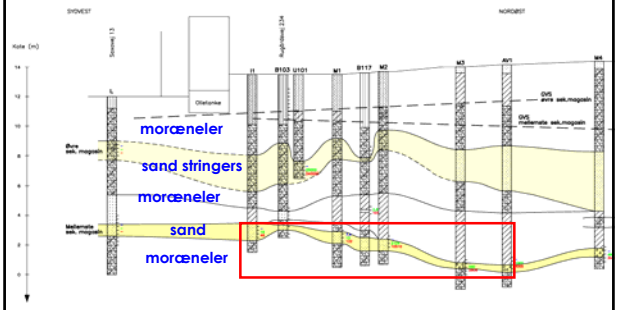
site geology



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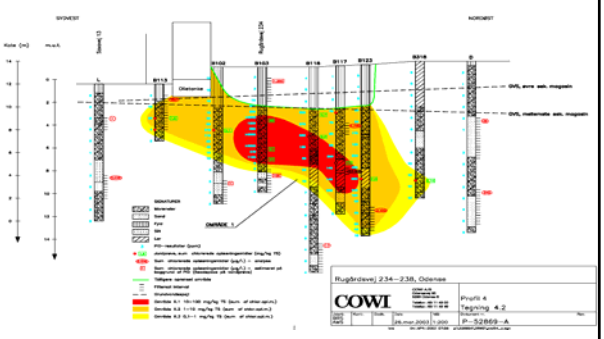
soil contamination above sand layer



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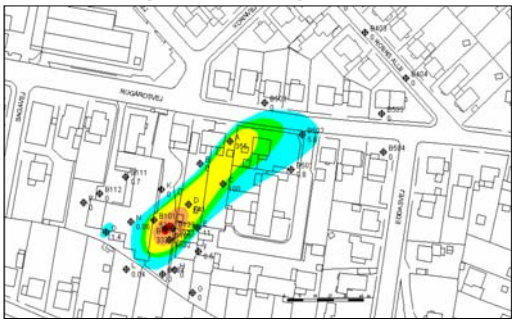
total chlorinated ethenes- in sand layer, before pilot test



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cis-1,2-dichloroethene - in sand layer, before pilot test

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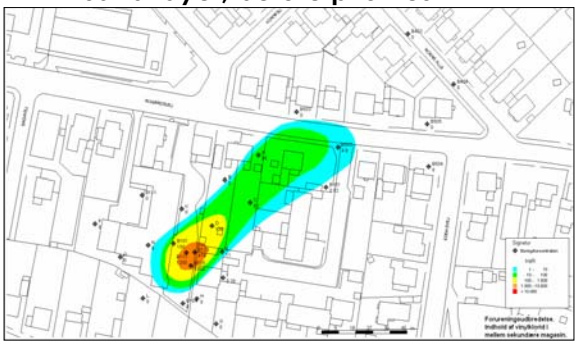
vinyl chloride - in sand layer, before pilot test



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ethene and ethane - in sand layer, before pilot test

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Pre-design Investigation: Bench Treatability Test

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bench treatability test - design

- 100g sediment
- 200mL ground water
- Electron donors: lactate and propionate (5mM)
- Initial TCE ~ 1500µg/L
- Bacterial culture KB1™ (200µL)
- 10°C
- Duplicate reactors

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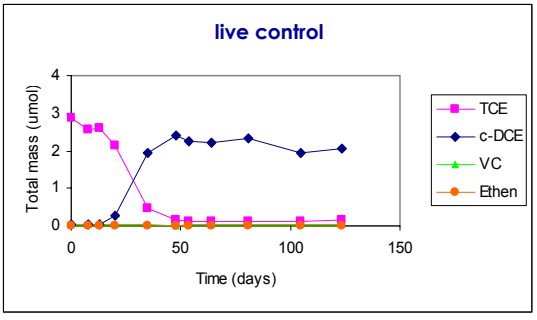
bench treatability test – example results



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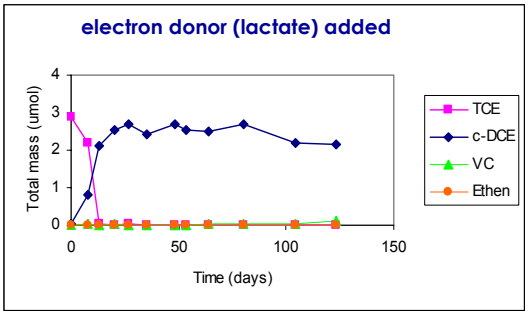
bench treatability test – example results



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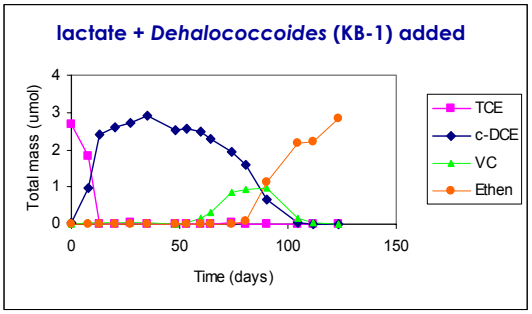
bench treatability test – example results



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Pre-design analysis: groundwater flow modeling

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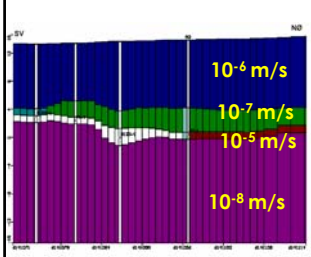
model construction



Tværsnit af modellens lag gennem B103, I1, B123 og M3

Zonering af lag 3

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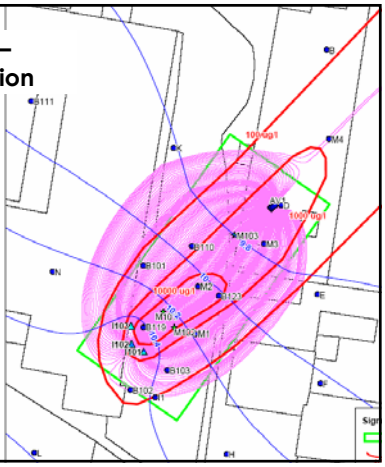
flow model results – optimal configuration

- 1 extraction well
- 3 injection wells
- 3 L/min recirculation rate
- Good overlap with plume
- Minimal spreading of plume
- 50 day residence time
- effective capture



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Pilot Test Design

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pilot test area layout

- 3 injection wells
- 1 extraction well
- 9 performance monitoring wells
- Amendment trailer
- Plot length = 29 meters

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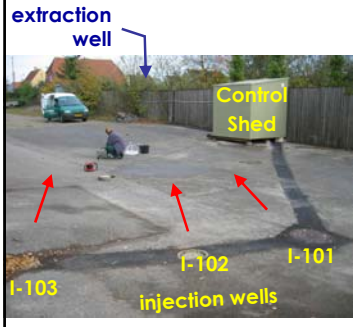
pilot test area layout



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pilot test – order of operations

- Months 1 & 2
  - Lactate addition – aquifer preconditioning
  - tracer test – quantify system hydraulics
- End of Month 2
  - One-time bioaugmentation – "seeding" aquifer with *Dehalococcoides*
- Months 3, 4, 5, 6, 7
  - continued lactate addition, recirculation
- Months 1 – 7
  - frequent performance sampling

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bioaugmentation… a Canadian invasion

- 9 L KB-1® (a *Dehalococcoides* culture) injected in each injection well

KB-1 ® Culture – Facts

- Sold by SiREM Laboratories, Canada
- natural, not engineered
- derived from aquifer material
- non-pathogenic
- injected at over 60 sites, including 3 sites in Denmark, 1 site in Sweden

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bioaugmentation… a Canadian invasion

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Pilot Test Results

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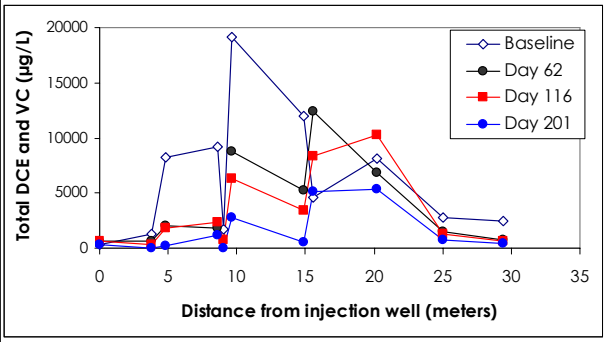
chloroethene trends during pilot test



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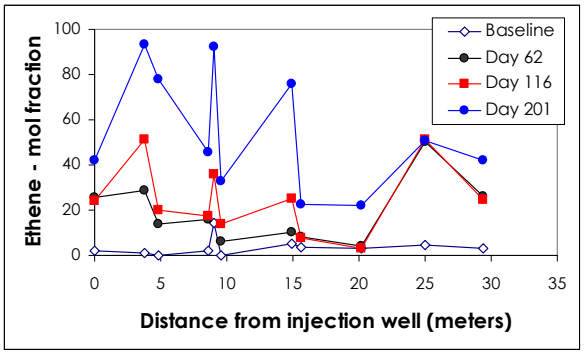
ethene production during pilot test



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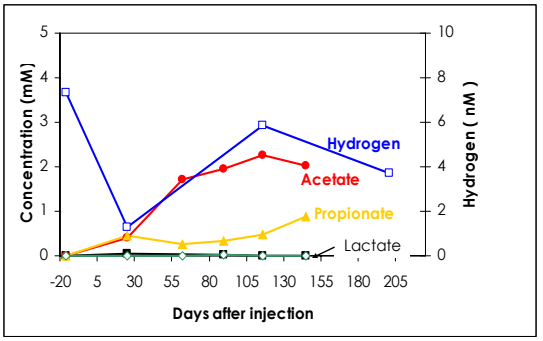
electron donor trends at M2, 14.9m from injection well



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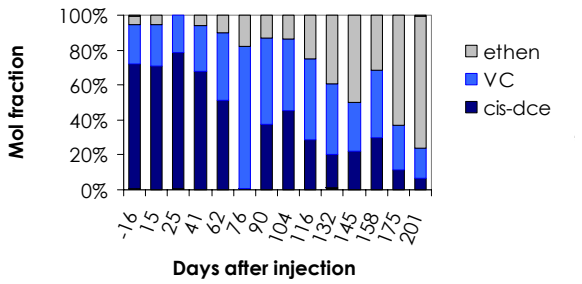
ethene & chloroethene mol fraction trends at M2, 14.9 m from injection well



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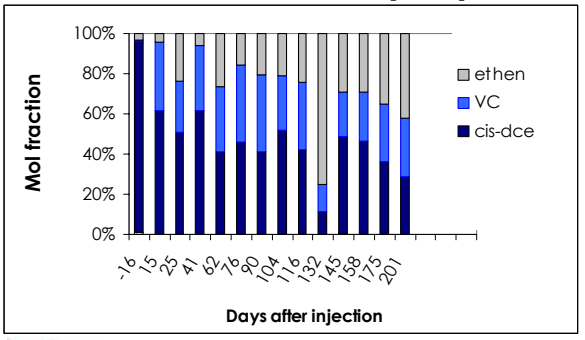
ethene & chloroethene mol fraction trends at extraction well (AV1)



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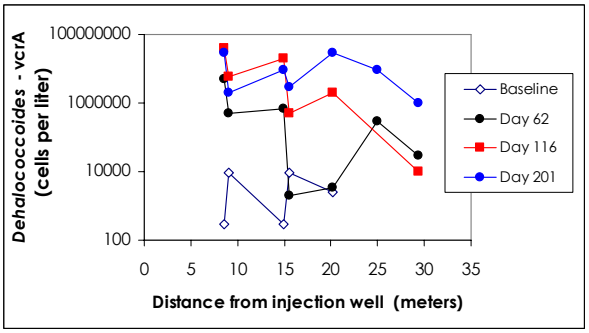
growth of *Dehalococcoides* during pilot test



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summary of findings

- biostimulation + bioaugmentation achieved significant destruction of chlorinated ethenes within 7 months
- cis-dichloroethene and vinyl chloride converted to ethene
- mol fraction of ethene increased to > 50% in all wells
- sodium lactate was an effective source of dissolved hydrogen (electron donor)
- infiltration and back diffusion of cDCE and VC from overlying clay extended duration of remediation

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conclusions and recommendations

- if infiltration and back diffusion of cDCE and VC from clay had not occurred, we could have completely remediated sand layer within 1 year
- at Rugardsvej 234, good ethene generation was observed with biostimulation alone
- cost of bioaugmentation = 3% of total project cost for this case
- stimulated reductive dechlorination is a simple and effective technology for Scandinavian sites

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conclusions and recommendations

- bioaugmentation necessary for some, but not all sites
- in general, bioaugmentation is most appropriate for chlorinated solvent sites where accelerated treatment is a primary objective

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