

# Monitoring enhanced anaerobic bioremediation at contaminated sites in the Netherlands

The use of specific monitoring tools

**TNO** | Knowledge for business



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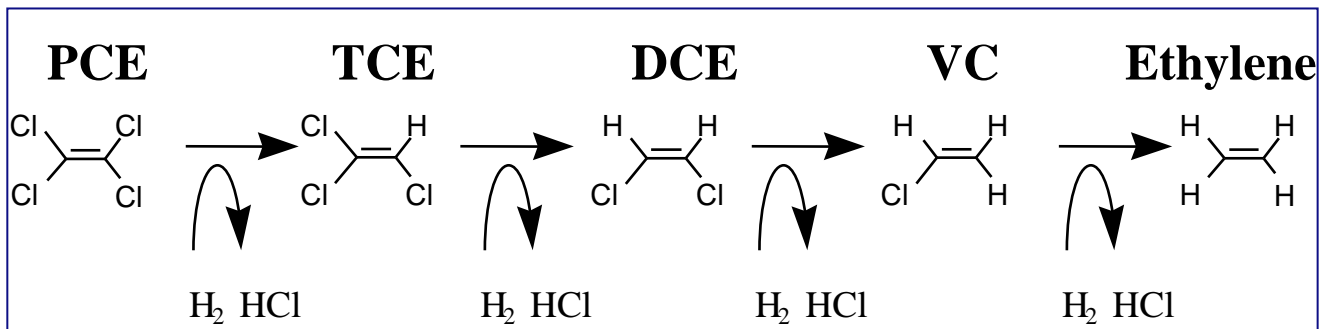
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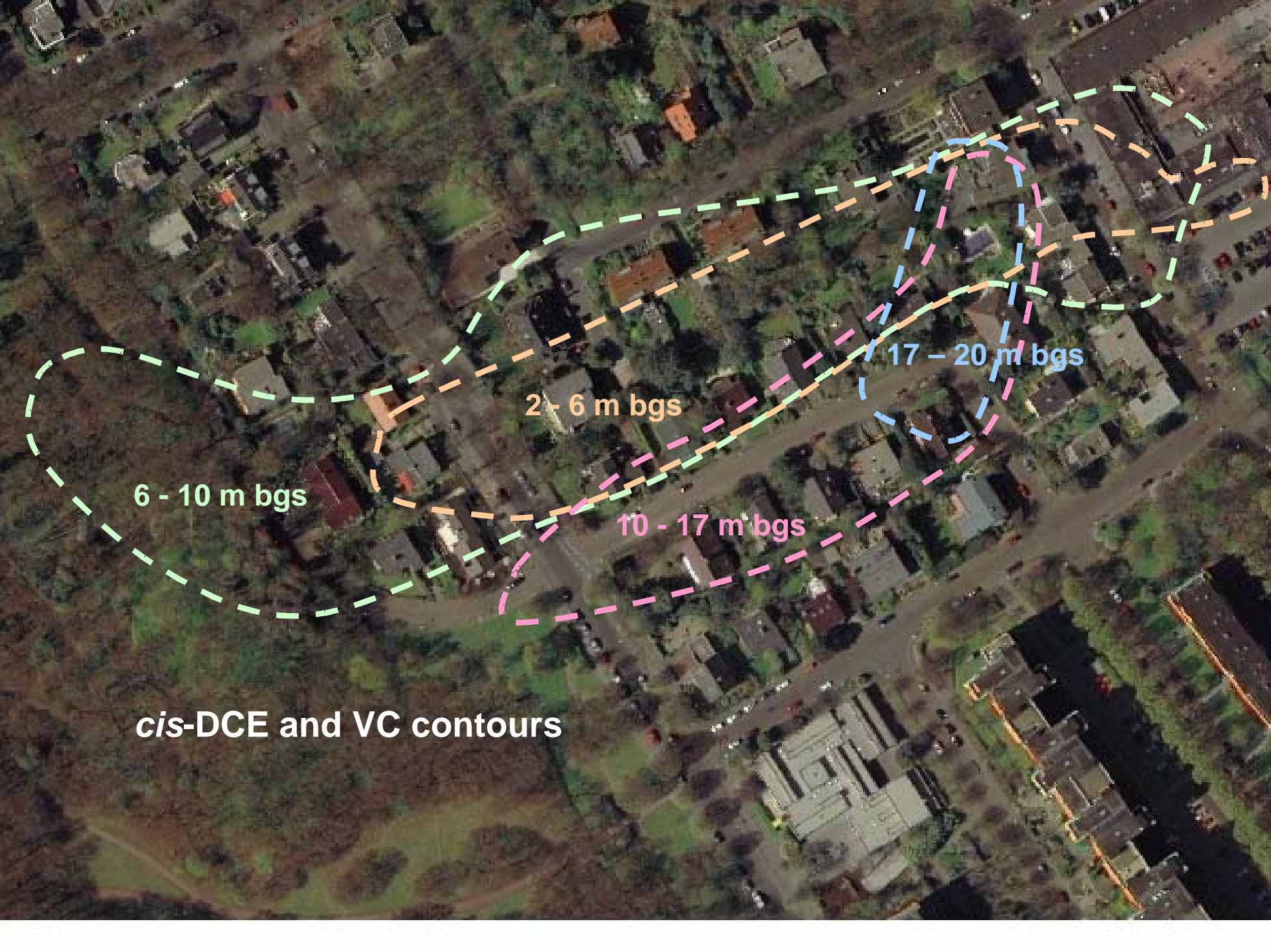
# Objectives

- Treatment of contaminated area
- Focus on source zone, plume will be treated afterwards
- Use of specific monitoring tools to demonstrate Enhanced Natural Attenuation
  - Hydrogen measurements at the site
  - Compound Specific Stable Isotope Analyses
  - Molecular analyses (DNA)

# Field characterisation

- Former dry cleaning in the city of the Hague, the Netherlands
- Contamination with PCE from 1975-1983, due to leaking sewage system
- At present; mainly DCE and VC





6 - 10 m bgs

2 - 6 m bgs

10 - 17 m bgs

17 - 20 m bgs

*cis*-DCE and VC contours

# Field characterisation



*Groundwater table*

$V_{gw}$

2

20 m  
bgs

# Field characterisation

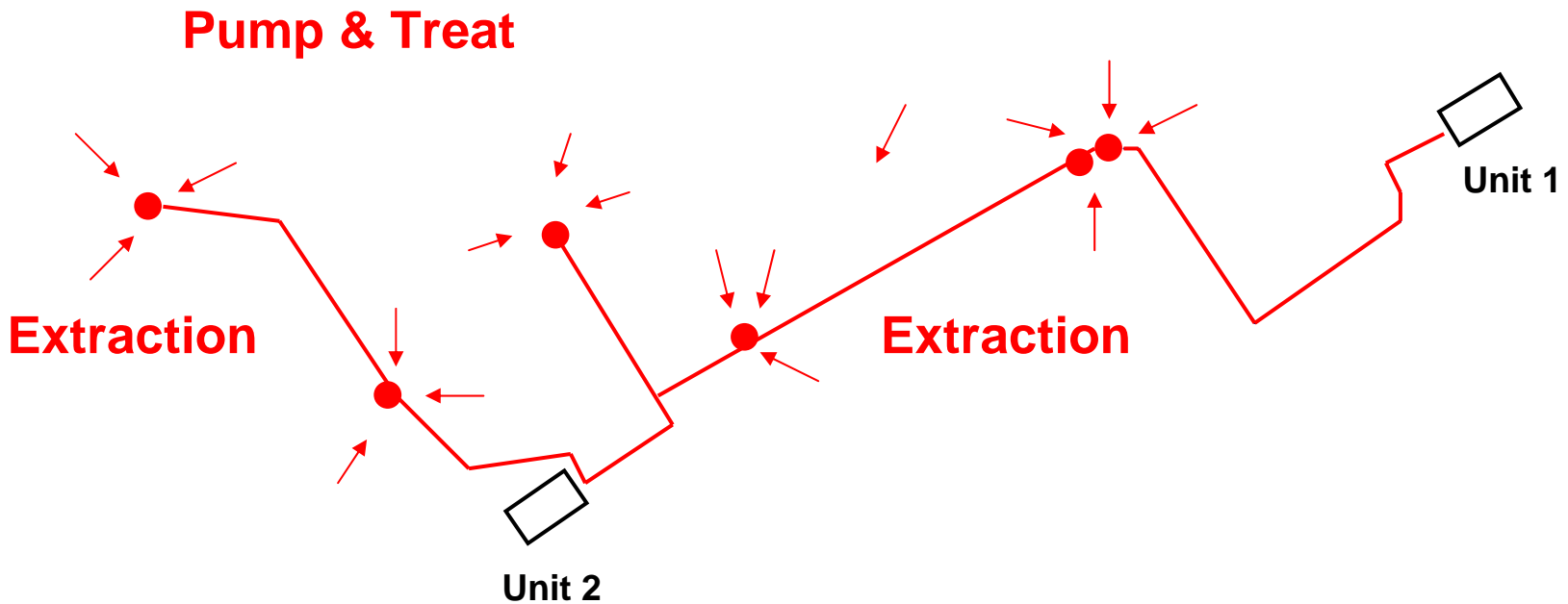
## Source zone

- Max. concentrations  
DCE 8,000  $\mu\text{g/l}$   
VC 5,700  $\mu\text{g/l}$
- Contaminated soil volume 35,000  $\text{m}^3$

## Boundary conditions

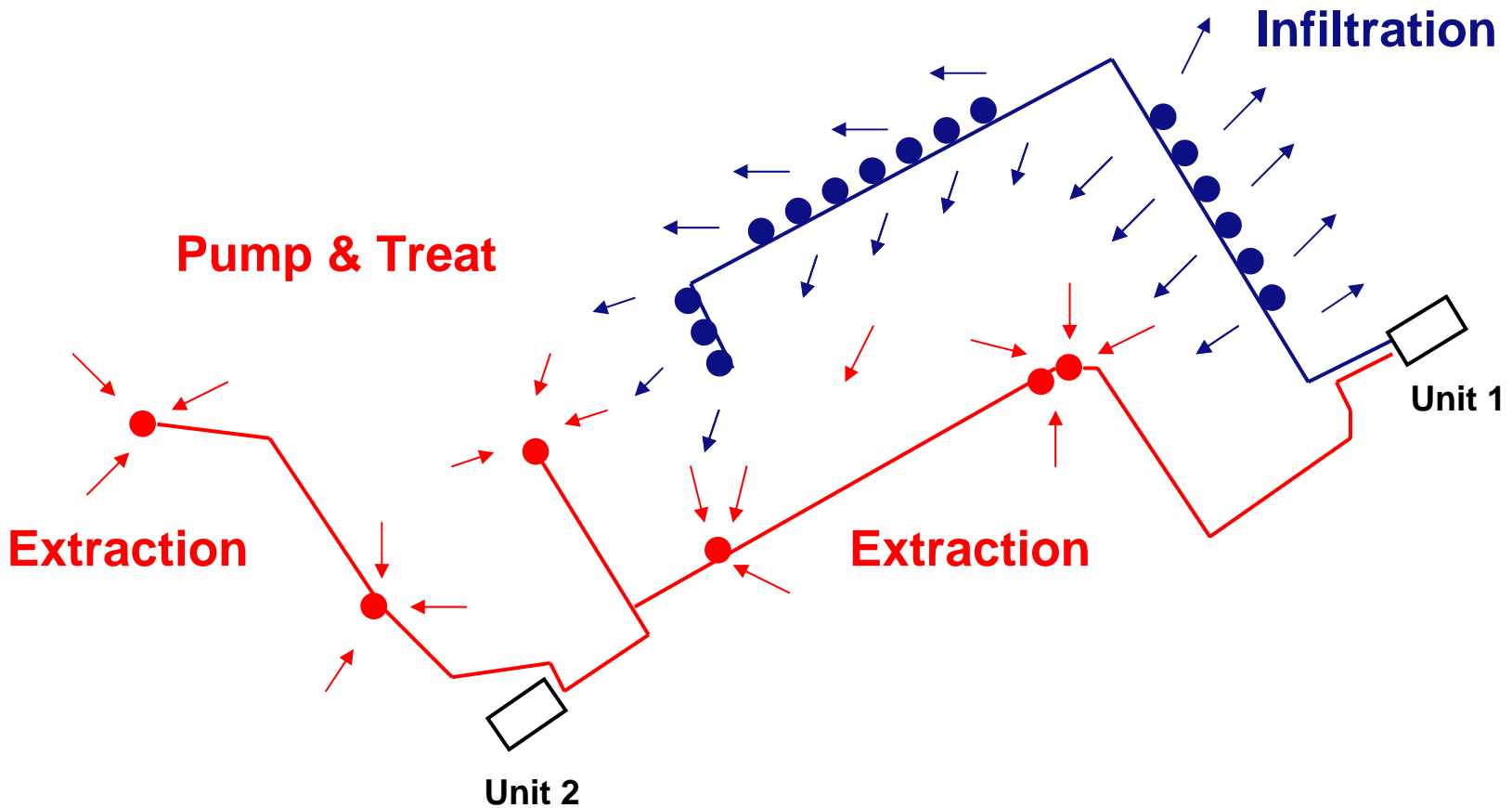
- Decrease in groundwater table max 0.3 m NAP (draught damage)
- Reach target value of 2.5  $\mu\text{g/l}$  VC within 10 years

# Enhanced bioremediation system

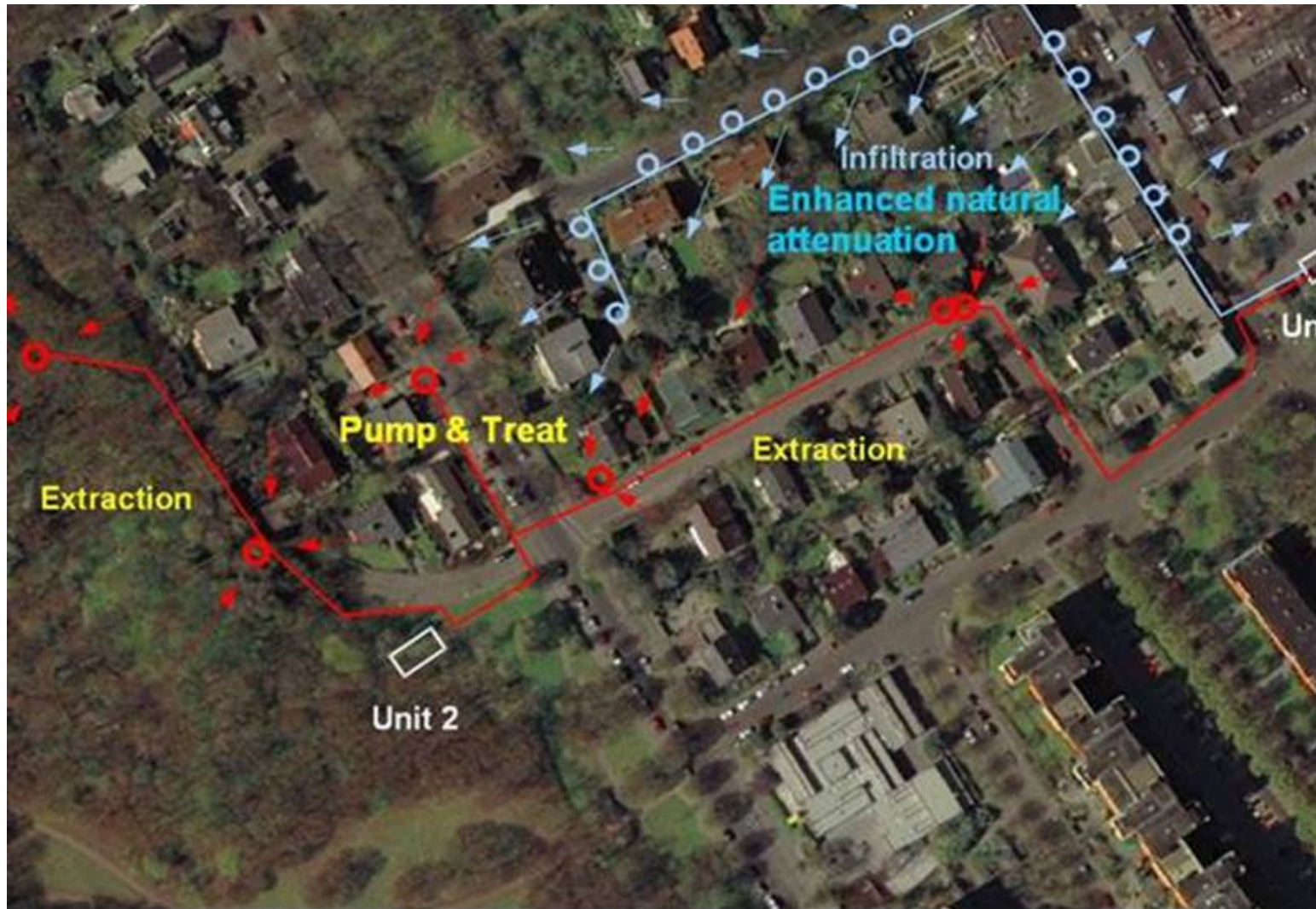




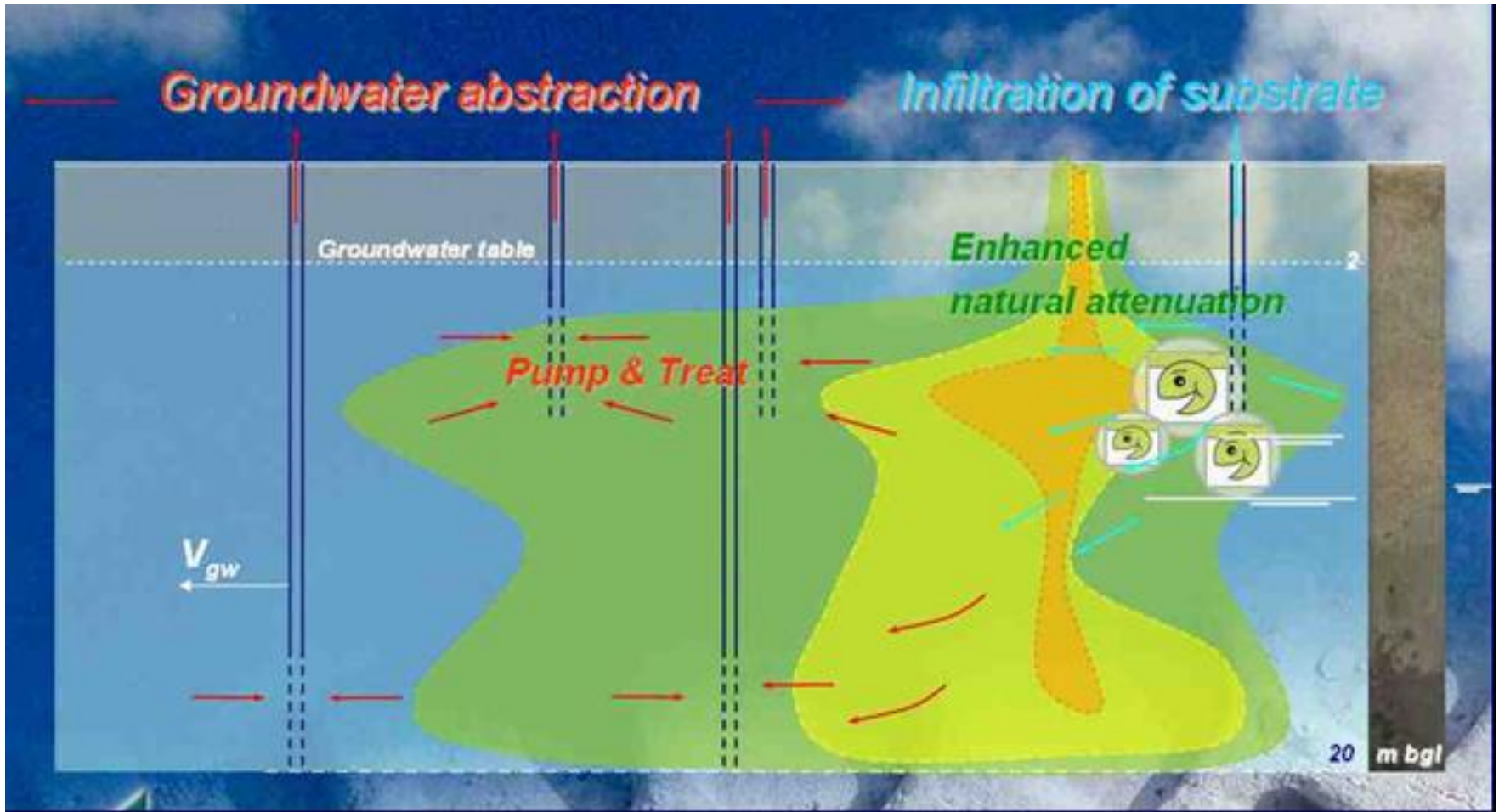
# Enhanced bioremediation system



# Enhanced bioremediation system



# Enhanced bioremediation system



# Enhanced bioremediation system; installation



# Enhanced bioremediation system; installation



Unit 1; Infiltration



Unit 2; Air stripper

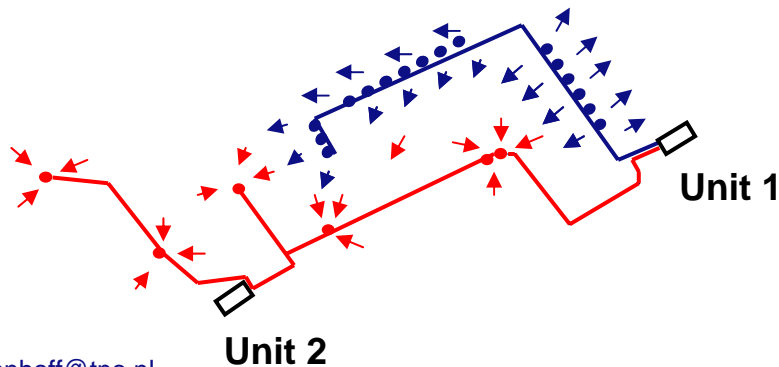
# Enhanced bioremediation system; installation



Unit 1; Infiltration

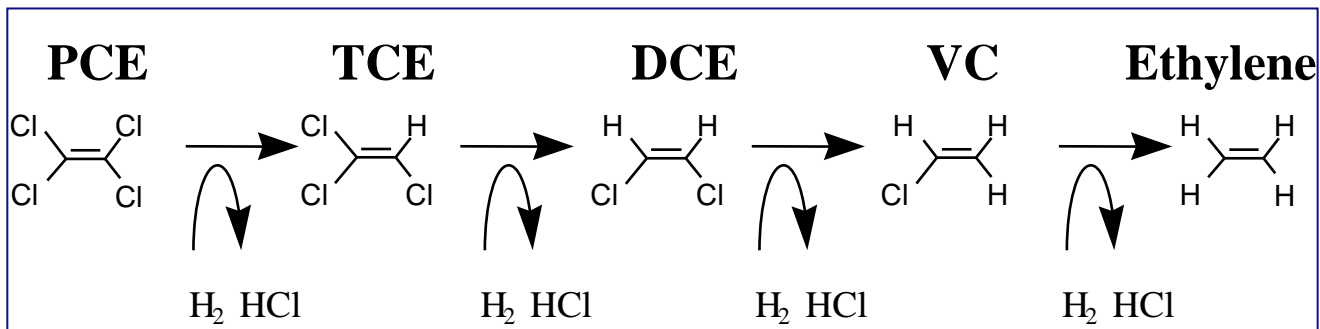


Unit 2; Air stripper



# Enhanced bioremediation system

- Combination of Pump & Treat, and Infiltration
- Source zone
- Reductive dechlorination by addition of electron donor
  - Acetic acid
  - Lactic acid

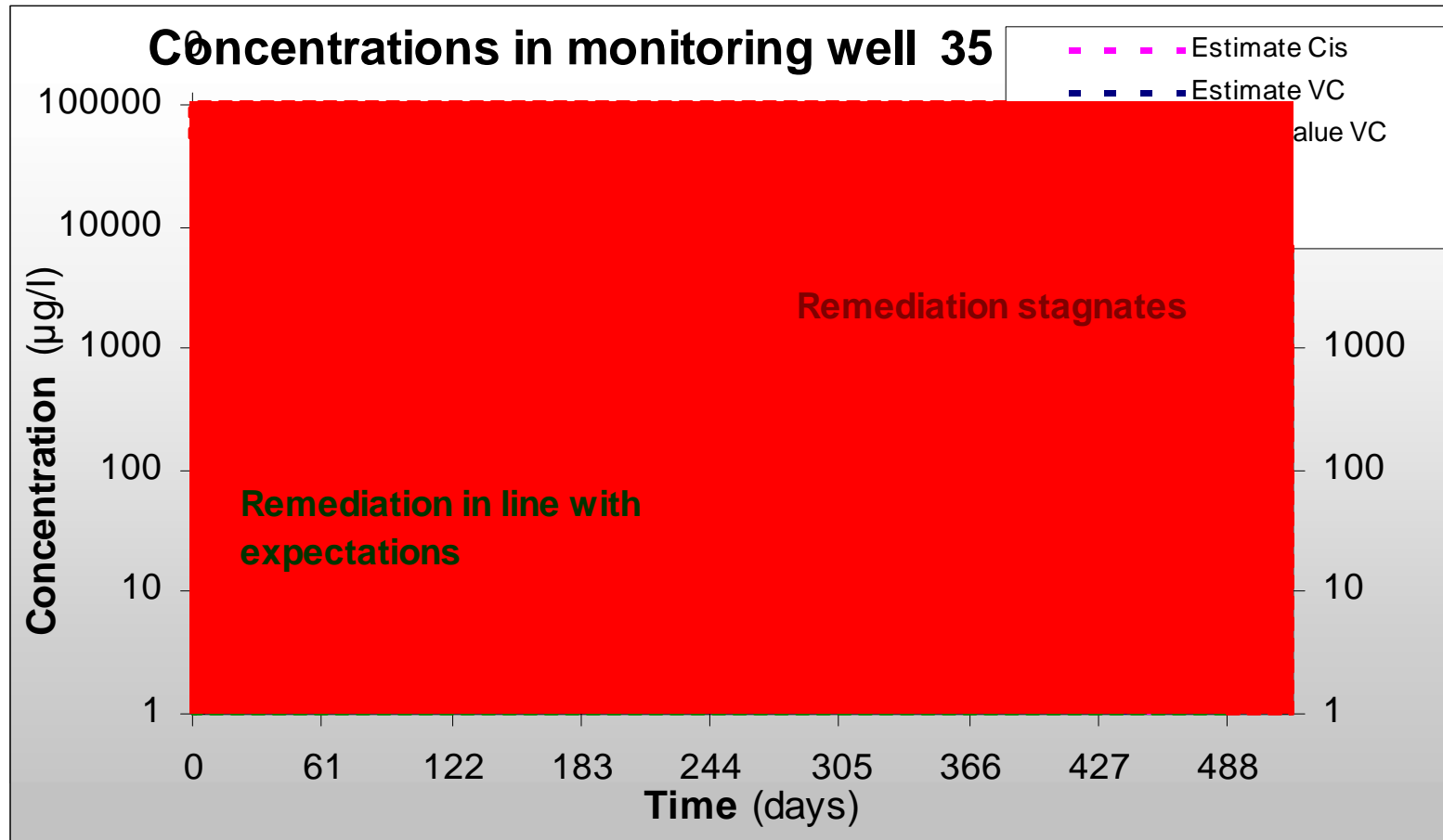


# Field results, source zone

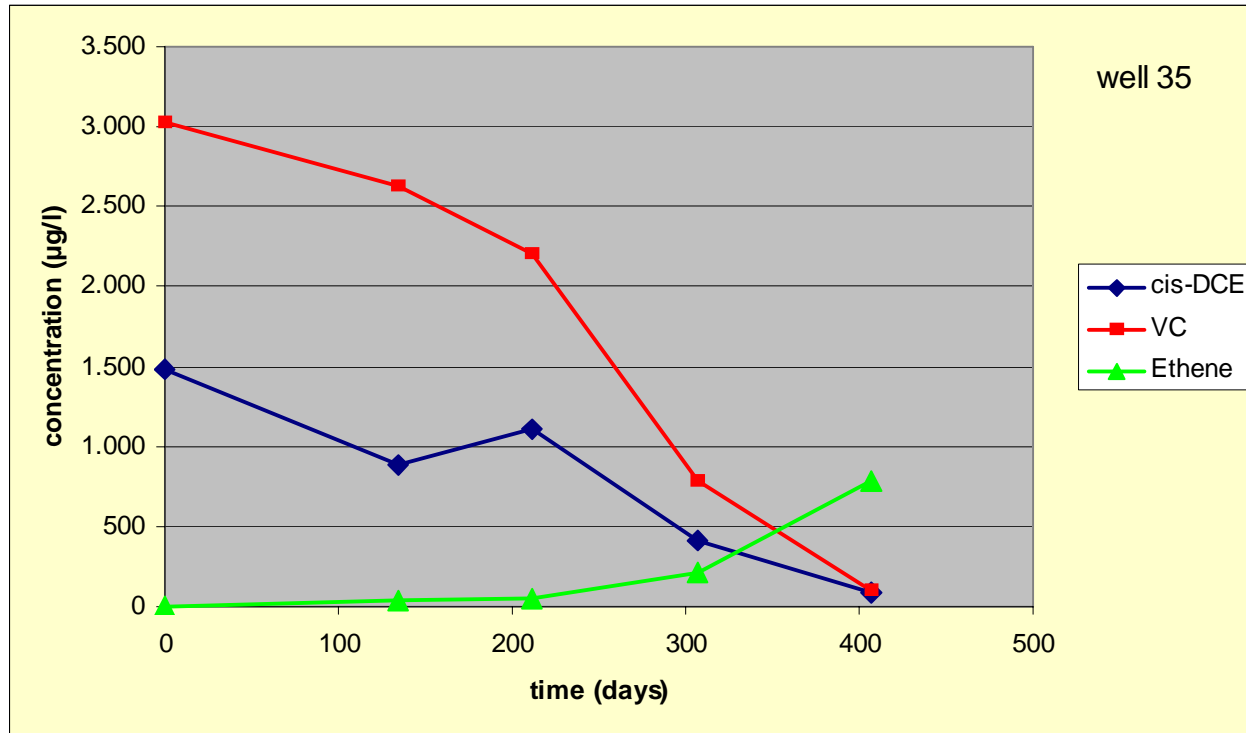
- 22,500 m<sup>3</sup> of groundwater infiltrated during 6 months;
- 19 ton of electron donor added; mix of lactate and acetate (4,500 kg DOC, 185 mg/l)



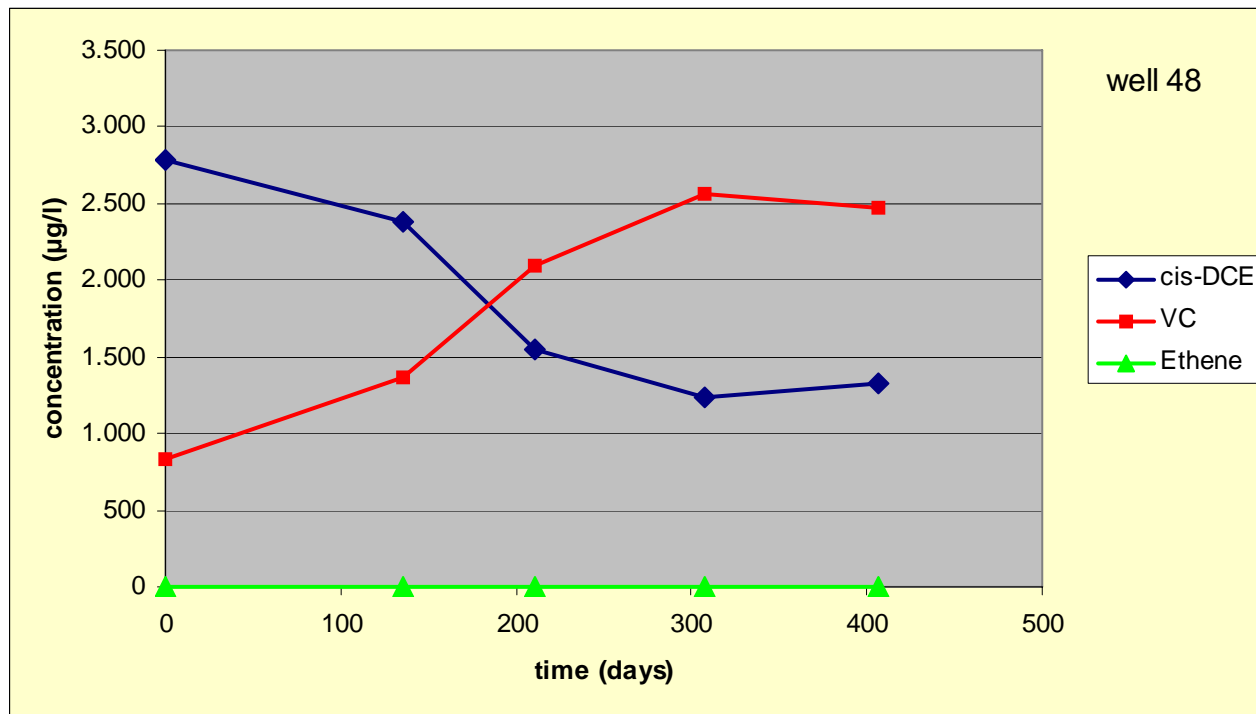
# Field results, source zone



# Field results, source



# Field results, plume

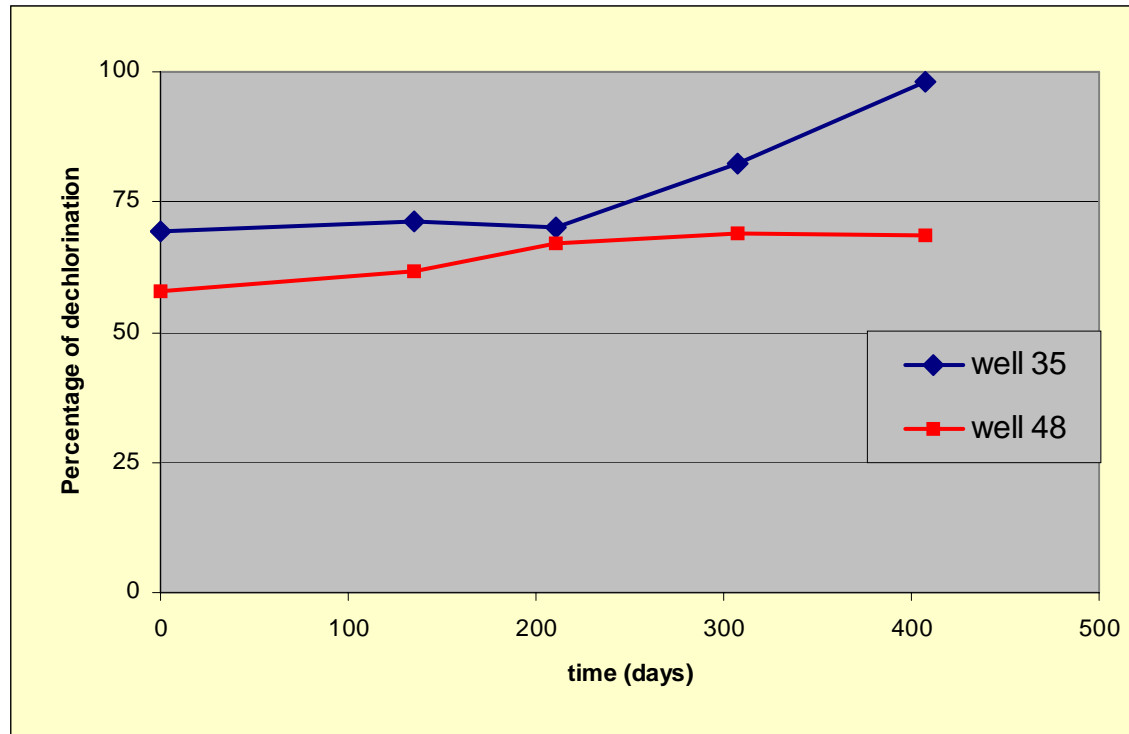


# Field results, percentage of dechlorination

- Good indication for dechlorination process
- Based on the ratio between parent and daughter compound
- To be calculated as follows (PCE as parent compound)

$$\frac{[\text{TCE}] + 2[\text{DCE}] + 3[\text{VC}] + 4[\text{Ethylene}] + 4[\text{Ethane}]}{4 \cdot ([\text{PCE}] + [\text{TCE}] + [\text{DCE}] + [\text{VC}] + [\text{Ethylene}] + [\text{Ethane}])} \cdot 100\%$$

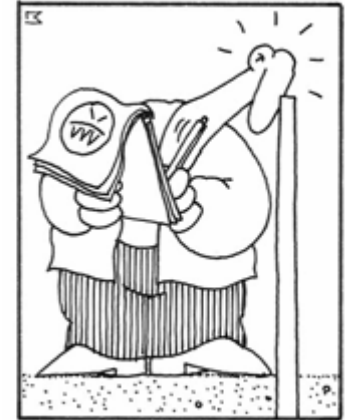
# Field results, percentage of dechlorination



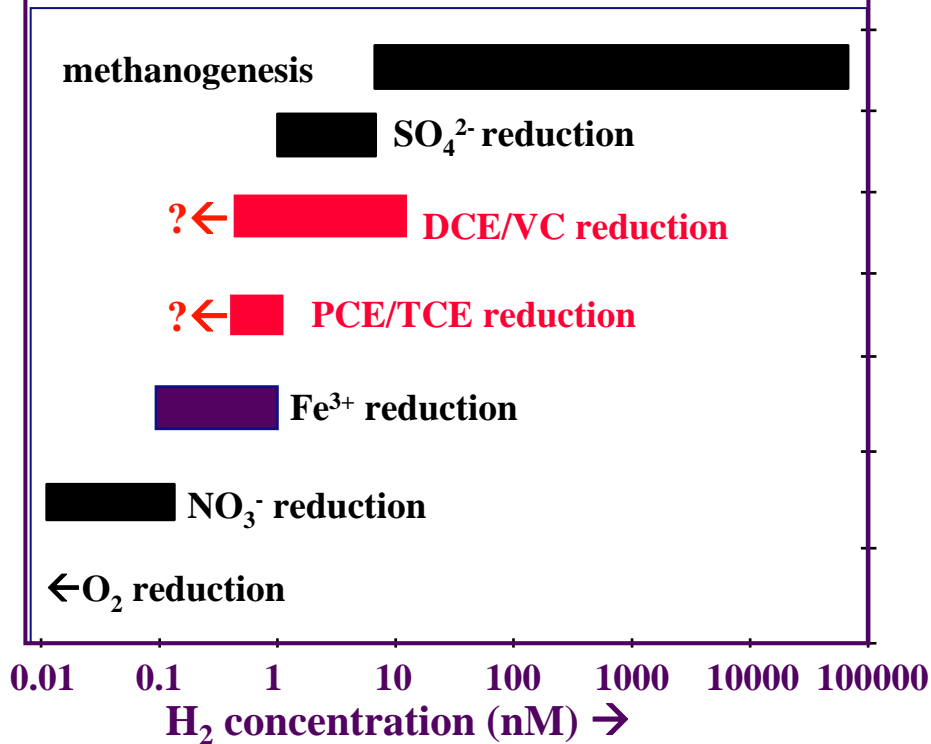
$$\frac{[\text{TCE}] + 2[\text{DCE}] + 3[\text{VC}] + 4[\text{Ethylene}] + 4[\text{Ethane}]}{4 \cdot ([\text{PCE}] + [\text{TCE}] + [\text{DCE}] + [\text{VC}] + [\text{Ethylene}] + [\text{Ethane}])} \cdot 100\%$$

# Field results, Hydrogen (H<sub>2</sub>)

Conditions suitable for dechlorination?

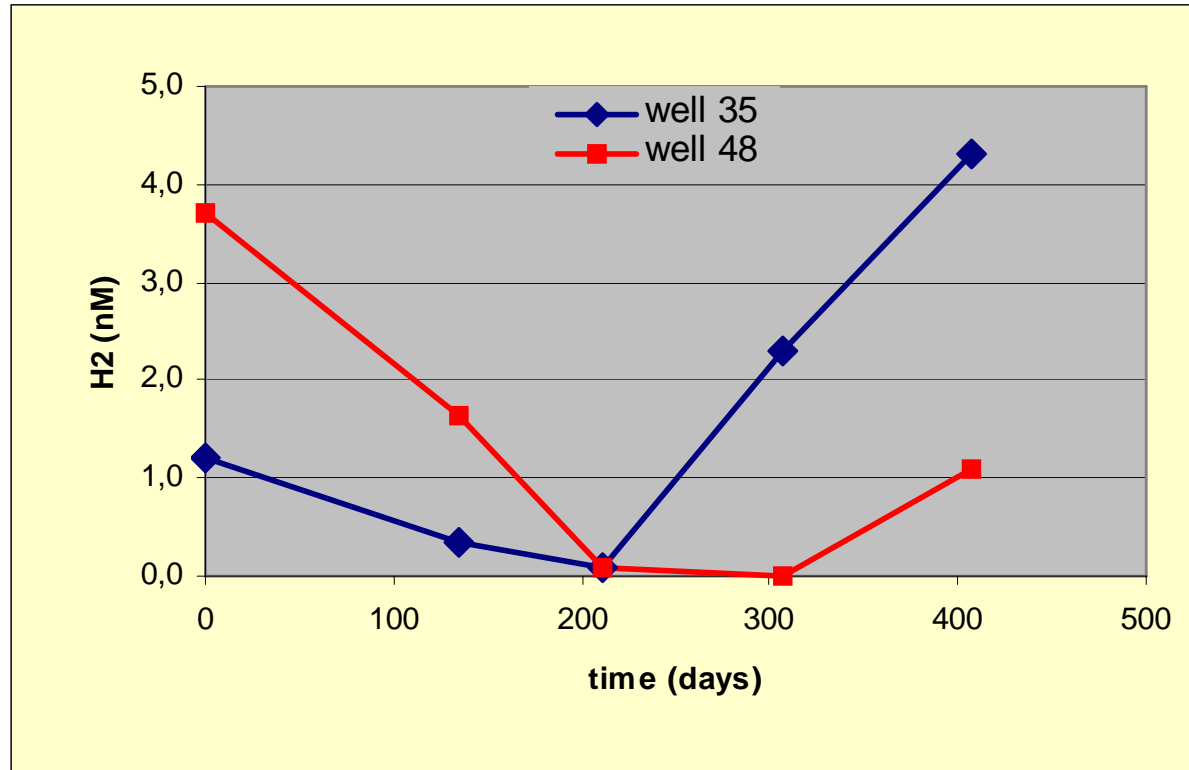


## Electron Acceptor Process



# Field results, Hydrogen (H<sub>2</sub>)

|            |   |                          |
|------------|---|--------------------------|
| < 0.1      | → | Nitrate reduction        |
| 0,2 to 0,8 | → | Fe(III)-reduction        |
| 1 to 4     | → | Sulphate reduction       |
| > 1        | → | Reductive dechlorination |
| 5 to 20    | → | Methanogenesis           |



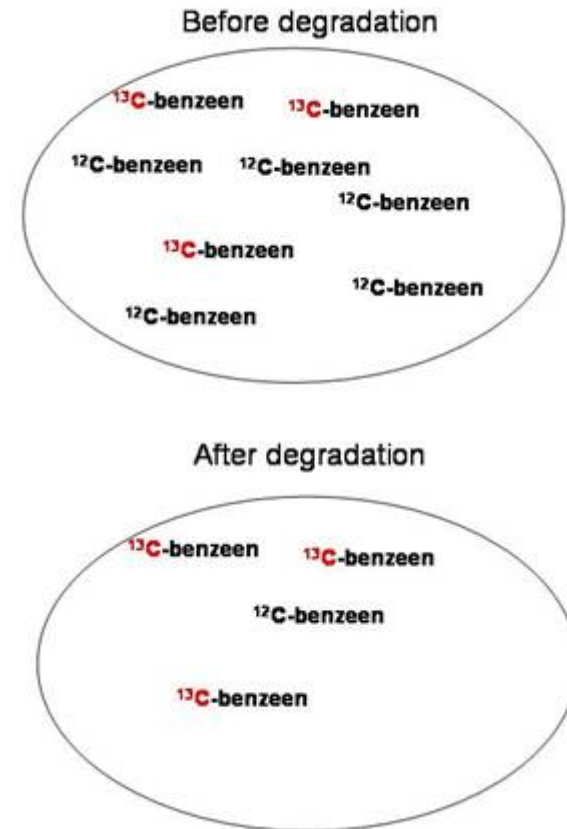
# Compound specific stable isotope analyses

- Which isotopes ?
  - Mainly  $^{12}\text{C}/^{13}\text{C}$  and  $^{37}\text{Cl}/^{35}\text{Cl}$
  - Other elements: S, O
- Why ?
  - Biological degradation; light isotope faster  
Enrichment of  $^{13}\text{C}$  -isotopes in residual parent compound (decrease in  $\delta^{13}\text{C}$ )
  - Dilution, adsorption and transport; no preference

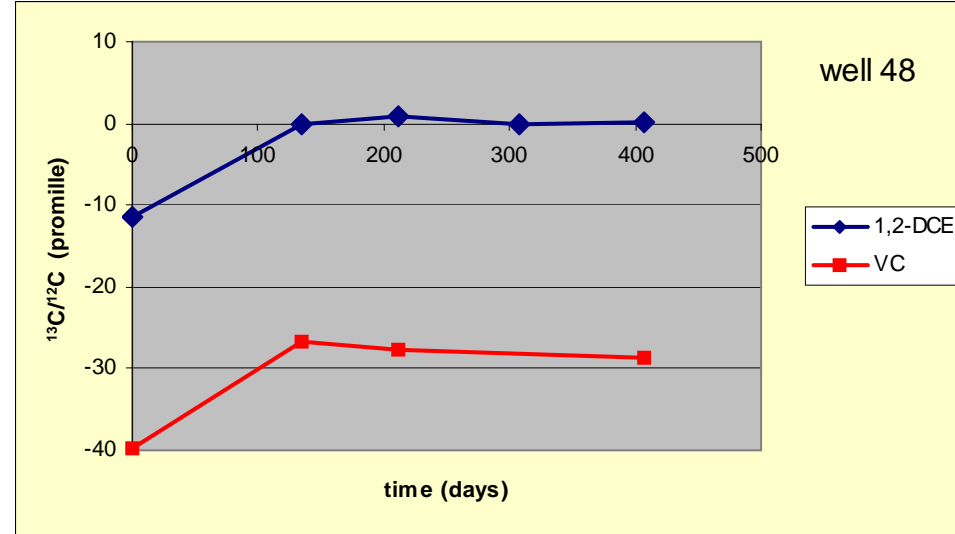
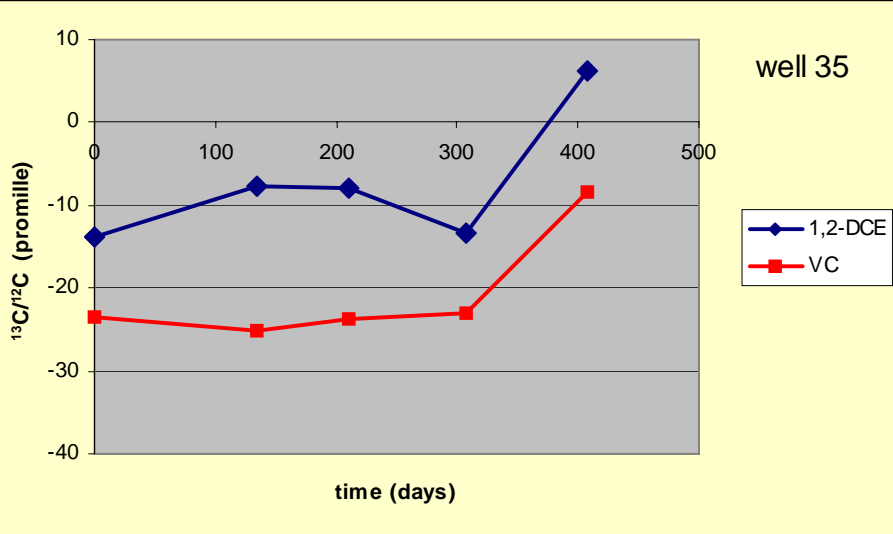


# Compound specific stable isotope analyses

- Biological degradation;  
light isotope faster
- Volatilisation;  
light isotope faster
- Dilution, adsorption &  
transport; no effect

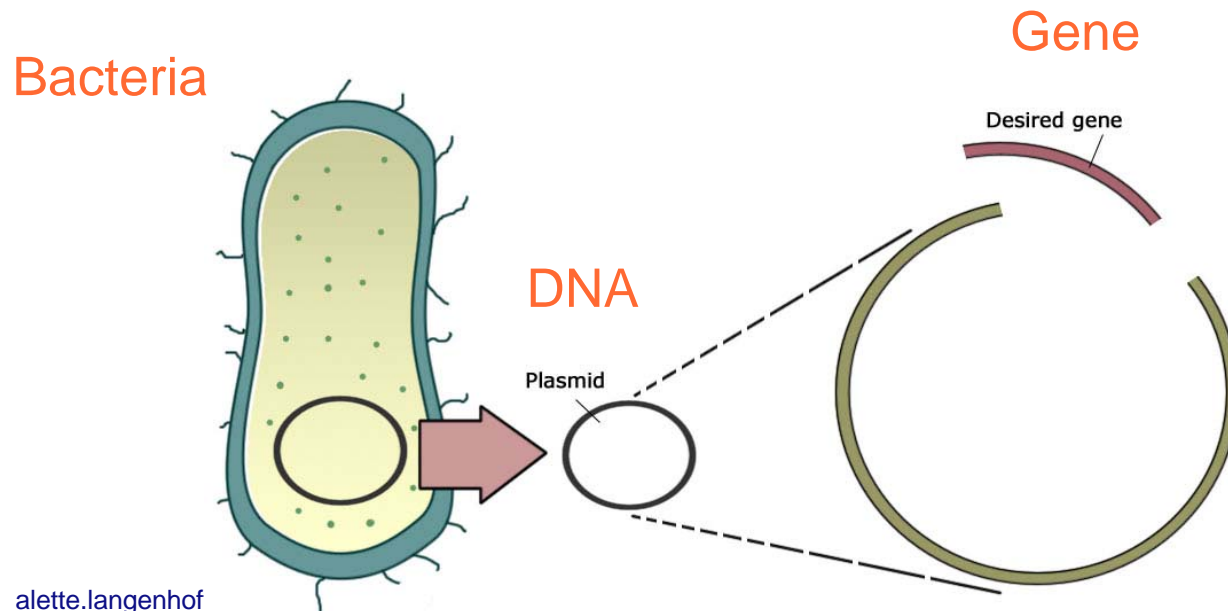


# Field results, Stable isotope analyses



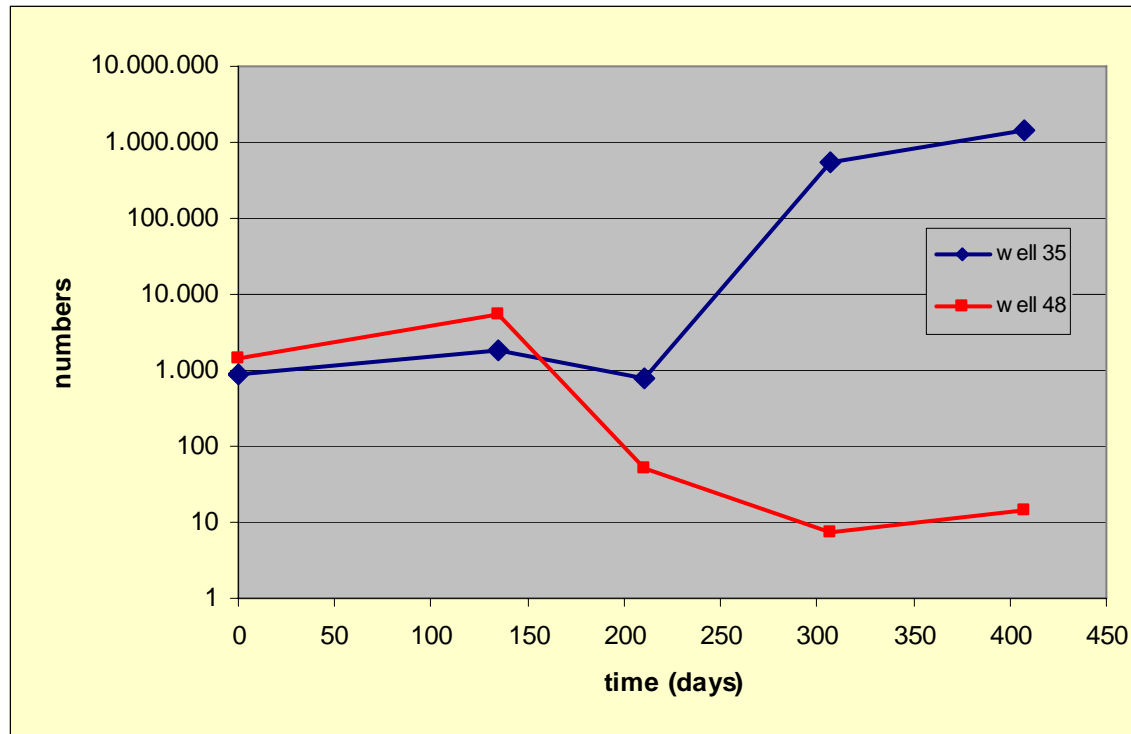
# Field results, DNA analyses (molecular detection)

- Detection on molecular level (e.g. DNA or RNA)
- Detection based on specific genes
- Gene: “part of DNA with information of a specific capacity”  
e.g. an enzyme or a type of bacteria

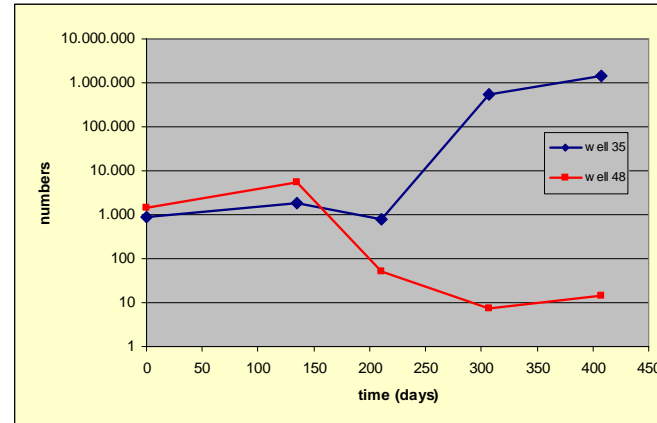
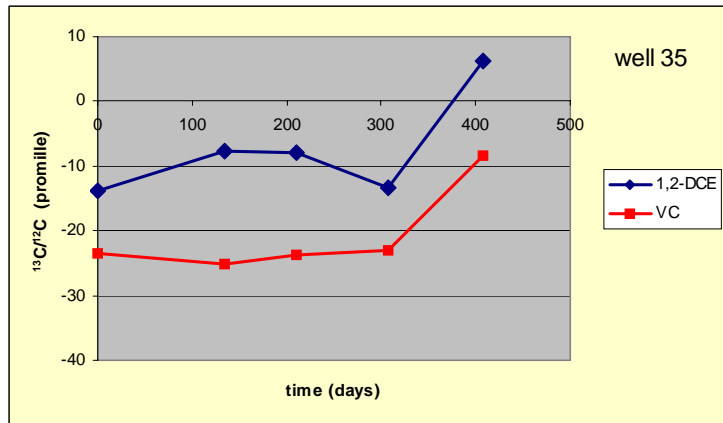
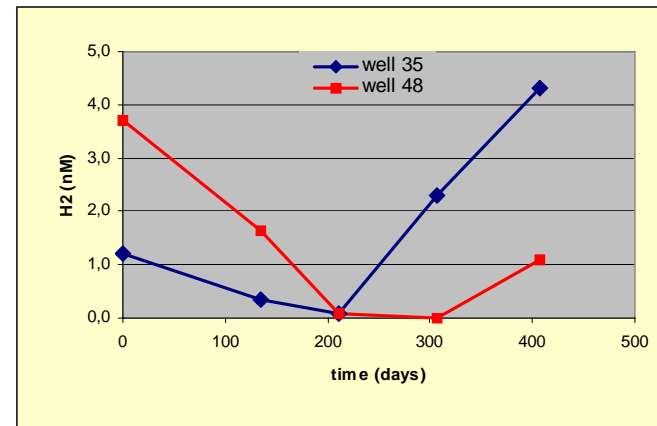
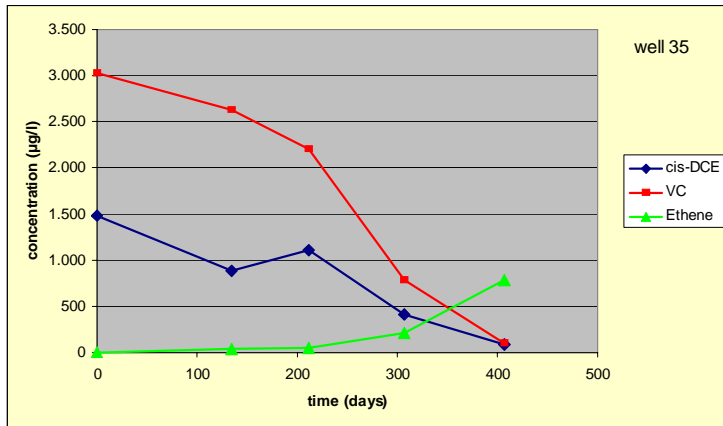


# Field results, DNA analyses

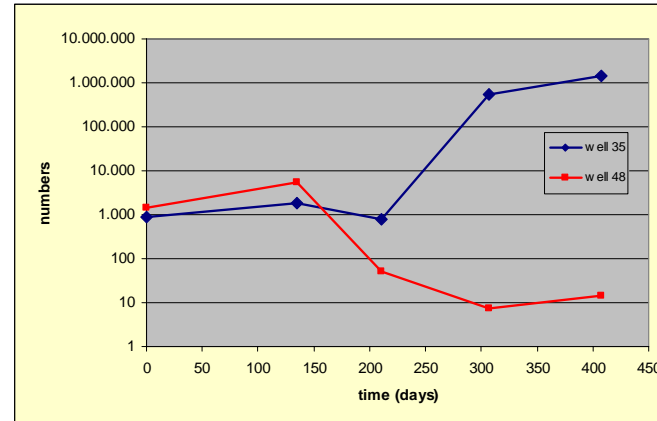
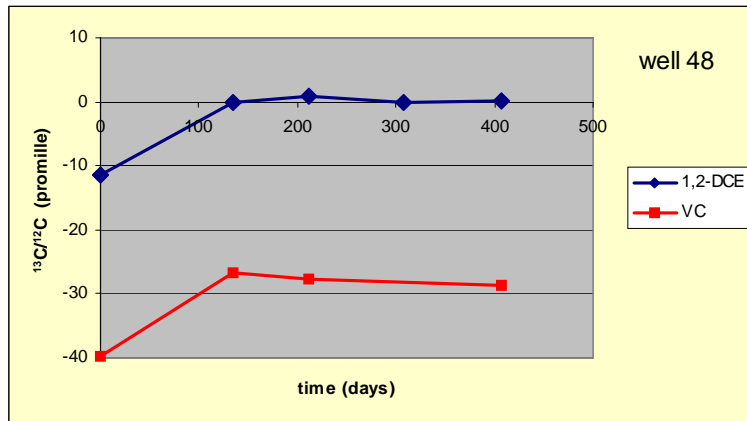
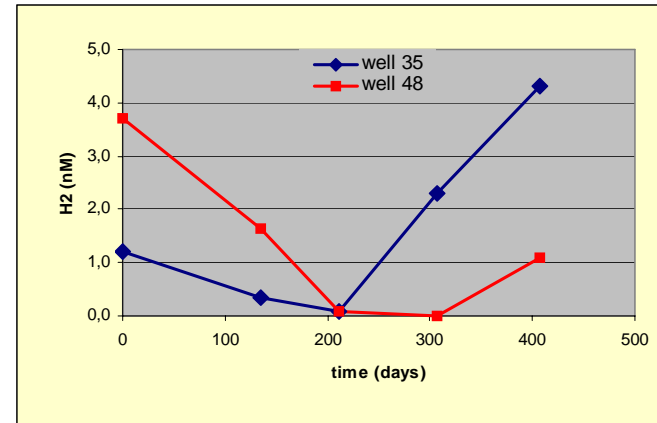
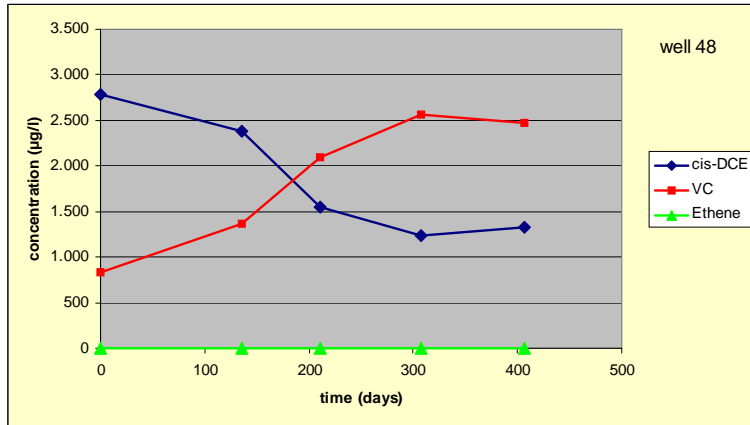
## *Dehalococcoides ethenogenes*



# Field results, source



# Field results, plume



# Conclusions

## System operation:

- Successful infiltration of substrate without clogging (22,500 m<sup>3</sup>, 4,500 kg DOC, 185 mg/l)
- Adapted extraction regime, due to restricted groundwater levels and other groundwater extractions in the area;
- Flexible infiltration/extraction regime needed;
- Spreading of electron donor in source zone, except deeper layer in plume.

# Conclusions

## Dechlorination takes place in source zone:

- Significant decreases in concentrations of *cis*-DCE (1,485 to 98 µg/l) and VC (3,021 to 55 µg/l);
- Suitable conditions for dechlorination ( $0.9 < H_2 < 10.2$  nM and DOC 126 to 170 mg/l);
- Fractionation of *cis*-DCE and VC, 20 and 15 promille;
- Increase of *Dehalococcoides ethenogenes* ( $> 10^6$ ).



# Conclusions

## Dechlorination less profound in plume

Initially pump and treat, followed by dechlorination

- Concentrations decrease slightly;
- Major concentrations in deeper aquifer (> 8 m bgs);
- Minor increase of H<sub>2</sub> concentrations (1.1 nM);
- Initial fractionation of *cis*-DCE and VC; but no further fractionation between day 100 – 400
- Decrease of *Dehalococcoides ethenogenes* since start (< 10<sup>3</sup>).

# Acknowledgement



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