



Anaerobic bioremediation of chlorinated compounds

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BioSoil R&D

IA Inteligência Ambiental

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Introduction

Introduction

- Introduction cVOC
- Enhanced Reductive Dechlorination (ERD)
- Practise
- Examples (projects)
- Shorten remediation time
- Specials

What are cVOC ?

chlorinated Volatile Organo Compounds

- Common soil pollution
- Compounds like tetrachloroethene (PCE), trichloroethene (TCE), trichloroethane (TCA), dichloropropane, chloroform
- Mainly used as solvent and degreaser (chemical cleaning, metal industry etc.)

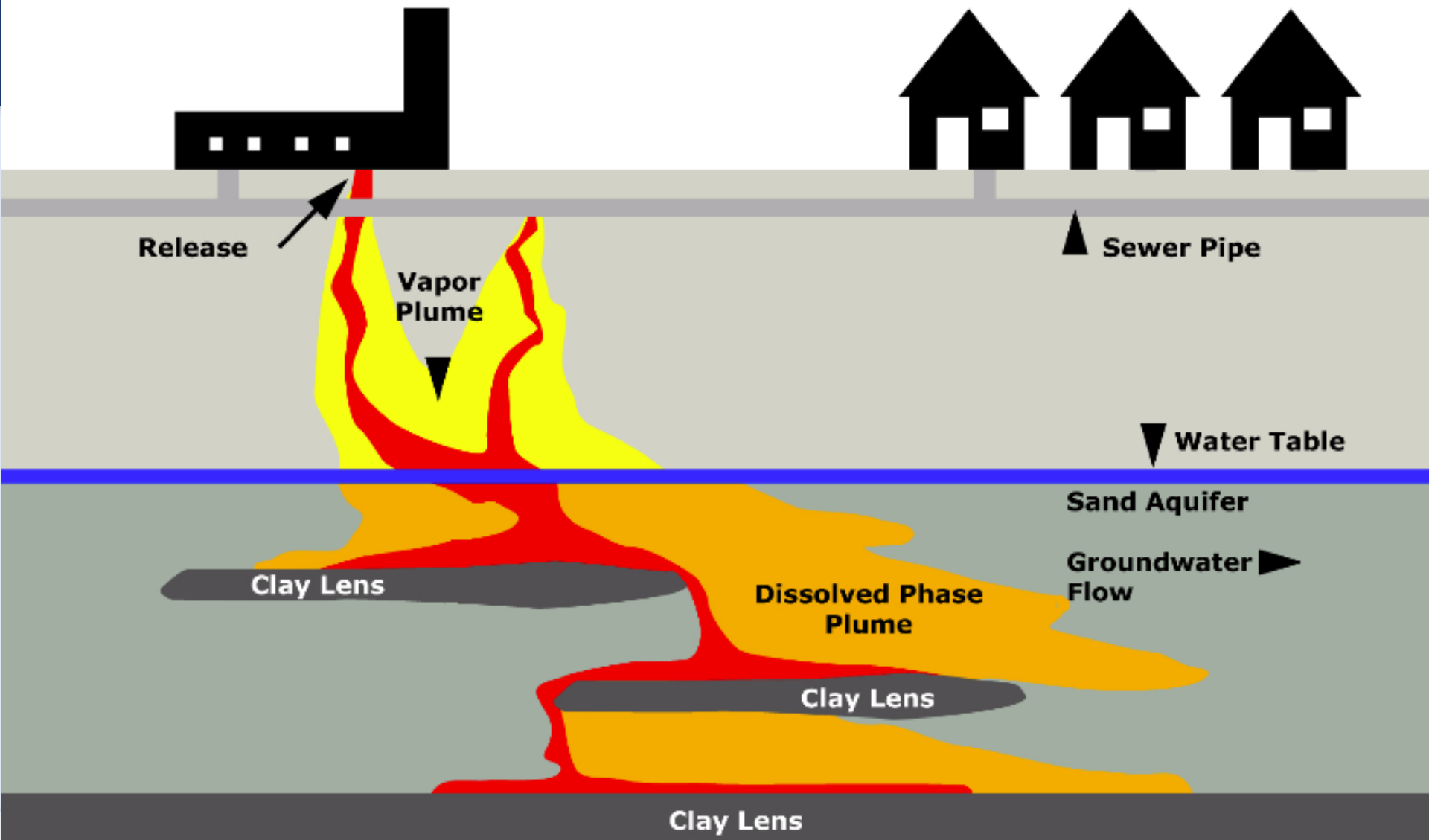
cVOC - introduction

Chemical characteristics

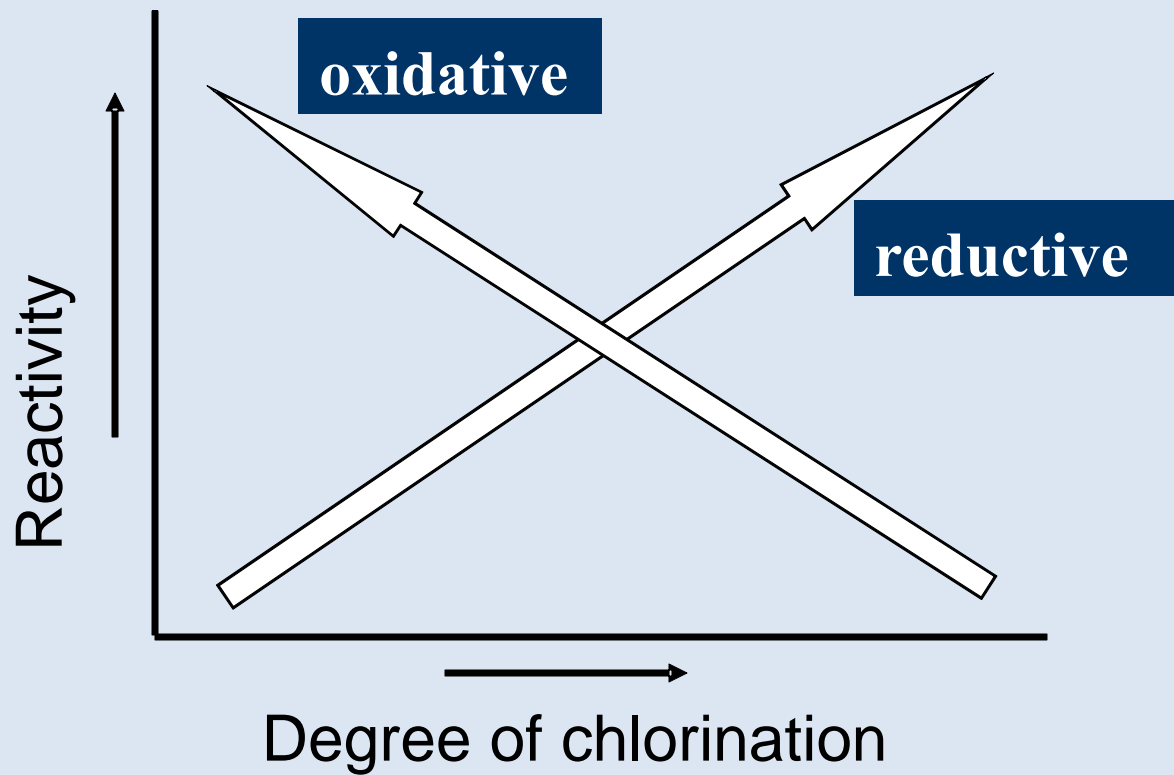
- Relative volatile
- Fairly water soluble (PCE 150.000 µg/l; I=40 µg/l)
 - Large plume
- Denser than water (DNAPI)
 - Often deep contamination (on impermeable layer)
- Adsorption coefficient (Koc) relative low
- Toxic ([suspect] carcinogenic)



The PCE Challenge



cVOC - degradation



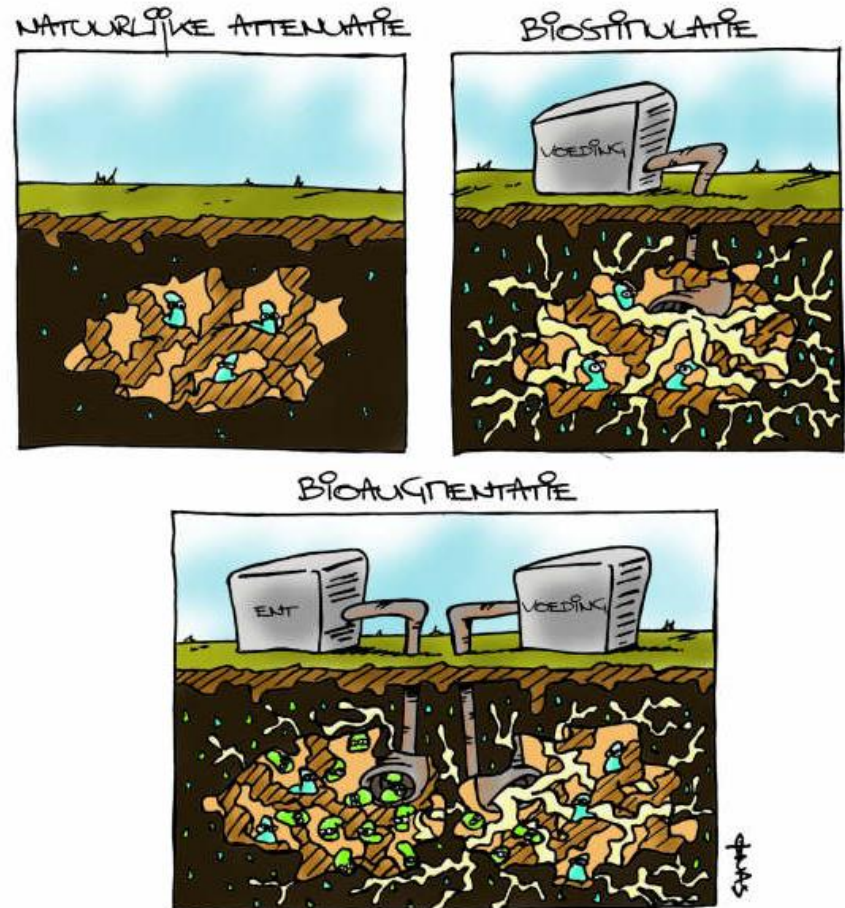
ERD - biostimulation

- **Bioremediation**
 - Natural attenuation
 - **Biostimulation**
 - Bioaugmentation

Principle biological
reductive dechlorination
(ERD)

=

Optimize conditions



Bioavailability determines duration of remediation

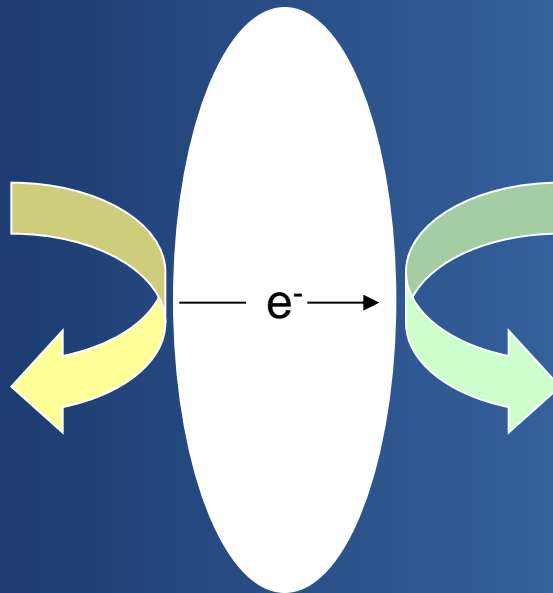
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Under (strong) reducing conditions
complete degradation of PCE to ethene
possible

Electron donor

**Percol[®], lactate,
molasse (H₂)**

CO₂, CH₄

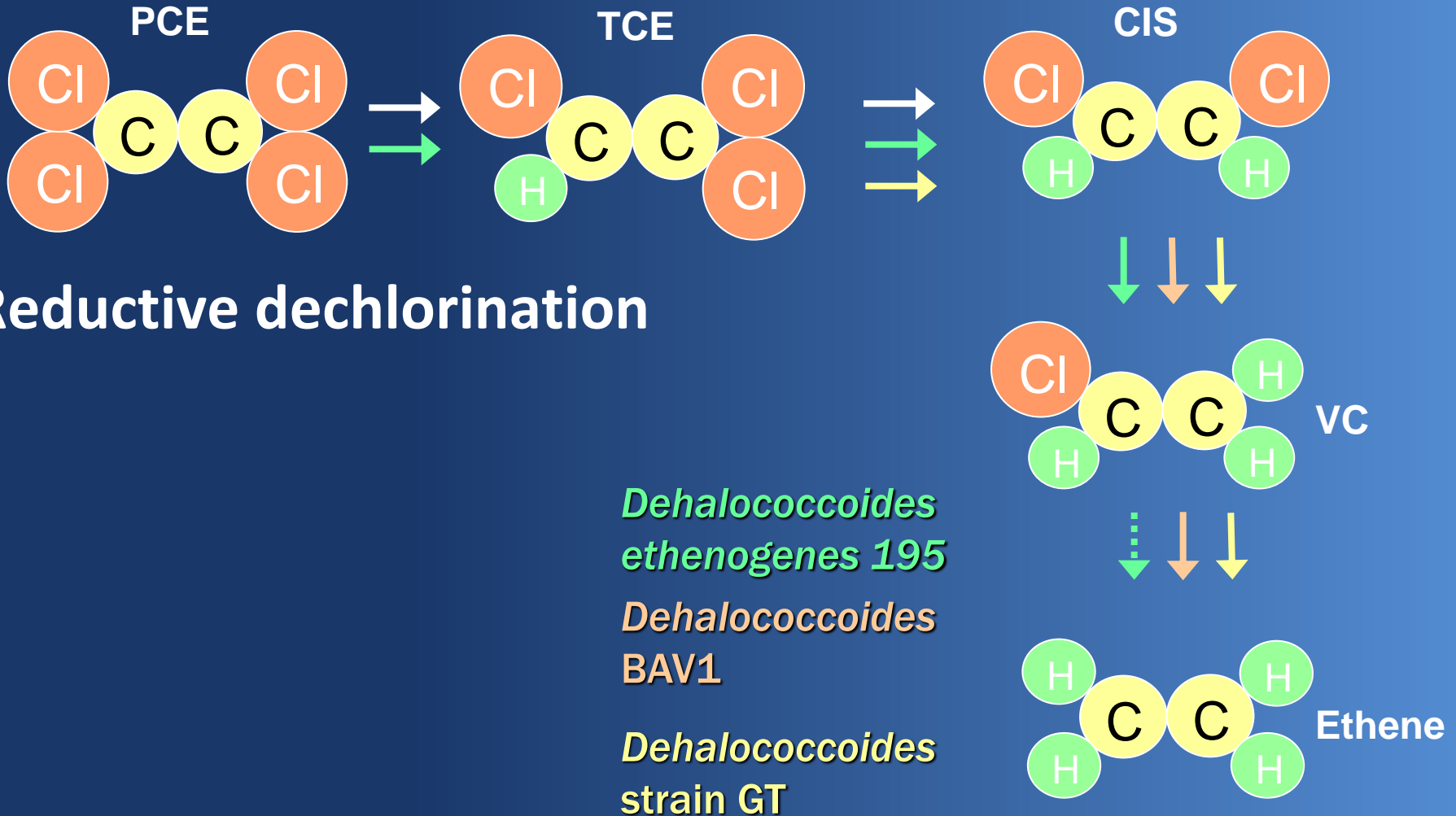


Electron acceptor

PCE/TCE/CIS/VC

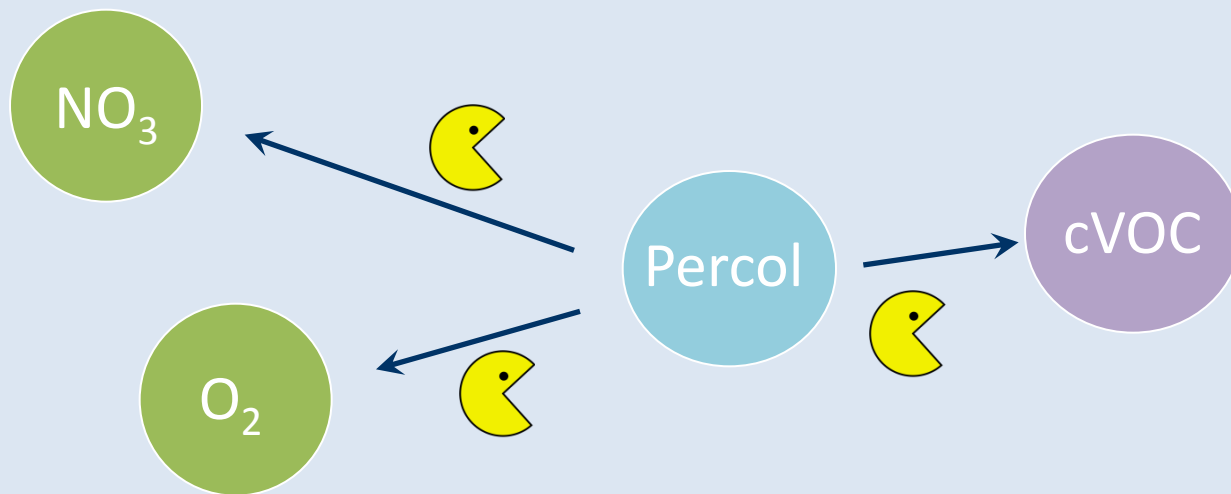
Ethene

Desulfitobacterium. Sulfurospirillum, Dehalobacter, Desulfuromonas

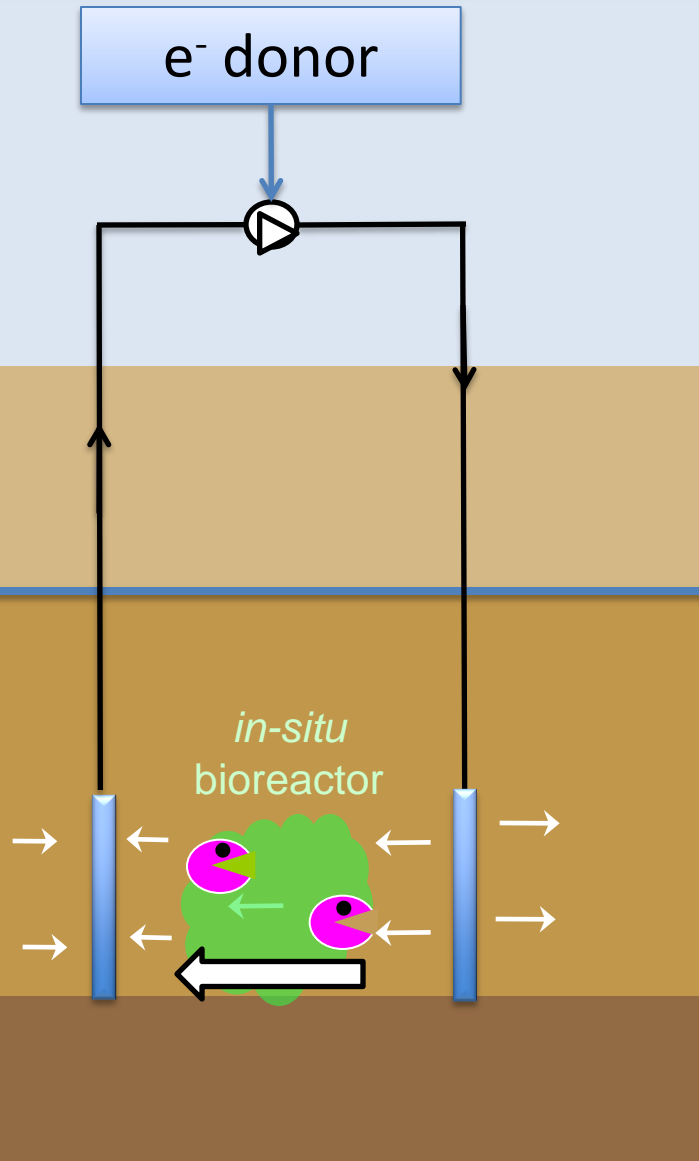


Effect complex electron donor two-fold:

- Reduce alternative electron acceptors (optimal redox)
- Substrate for reductive dechlorination cVOC



ERD - practice



ERD Installation

- Closed circulation system
- 'Continuous' circulation + 'continuous' substrate dosage
- Distribution e⁻ donor + bacteria + mobilization cVOC



ERD – general

In general

Enhanced reductive dechlorination (ERD) of chlorinated ethenes takes \pm 3-5 years

However, sometimes time is limited.....

Bottleneck's

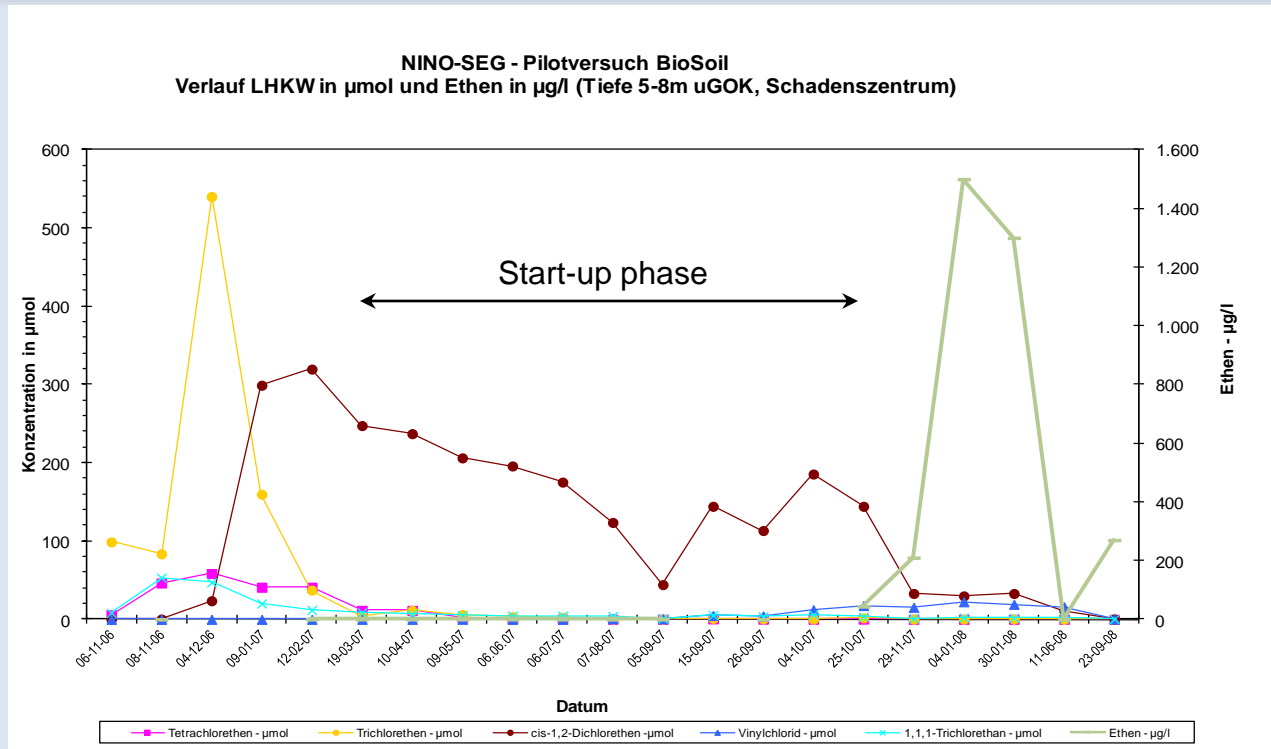
Assuming conditions are optimal:

- Bioavailability (mobilization, adsorptions, rebound)
- Start-up phase (especially when start conditions are poor)
- Source zone location

Project Nordhorn-Germany (cVOC)



Nordhorn – pilot test



Laboratory degradation test: stalled at CIS
Full-scale: complete dechlorination from the beginning

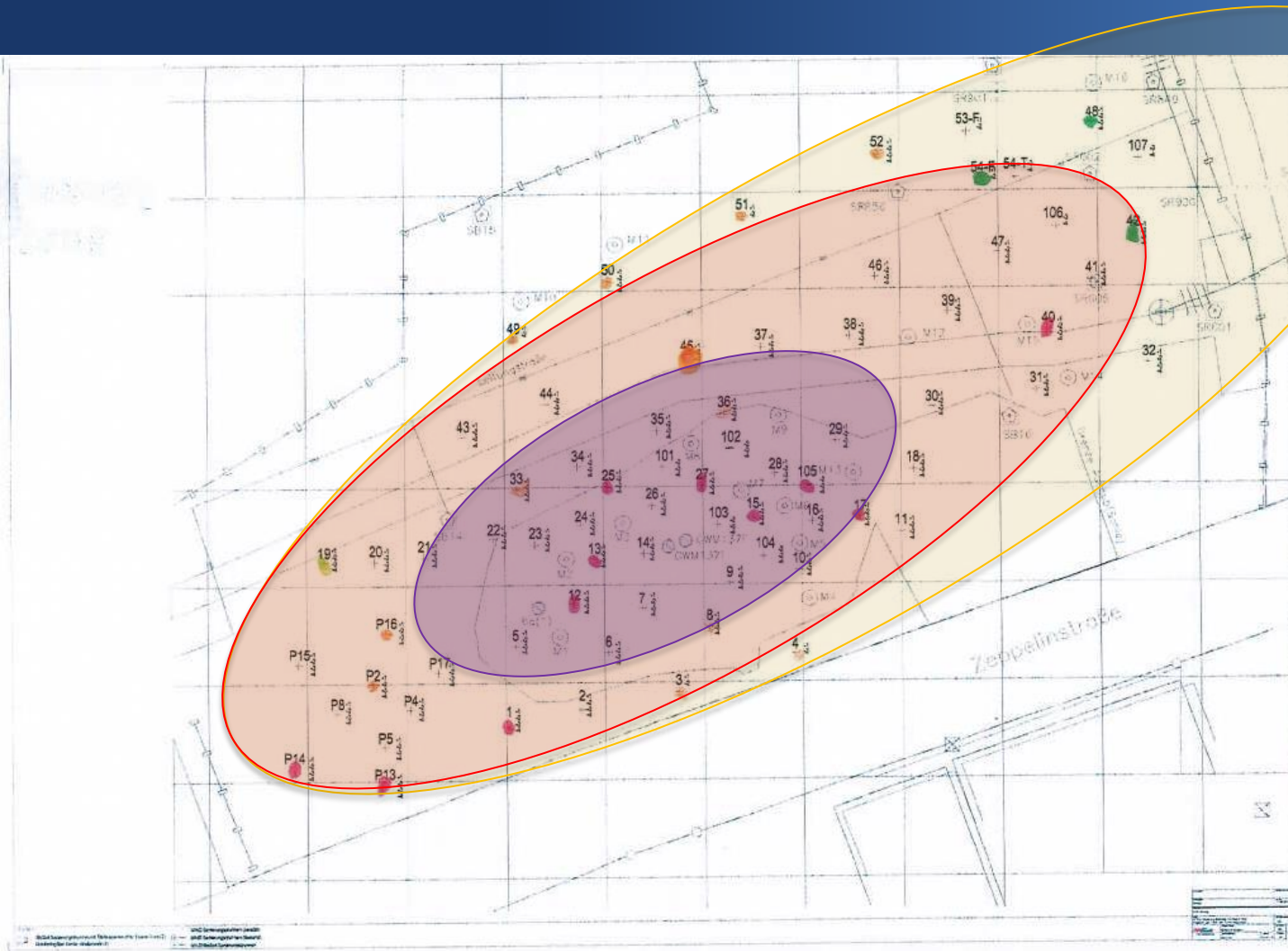
Nordhorn - start remediation

Situation Summer 2008

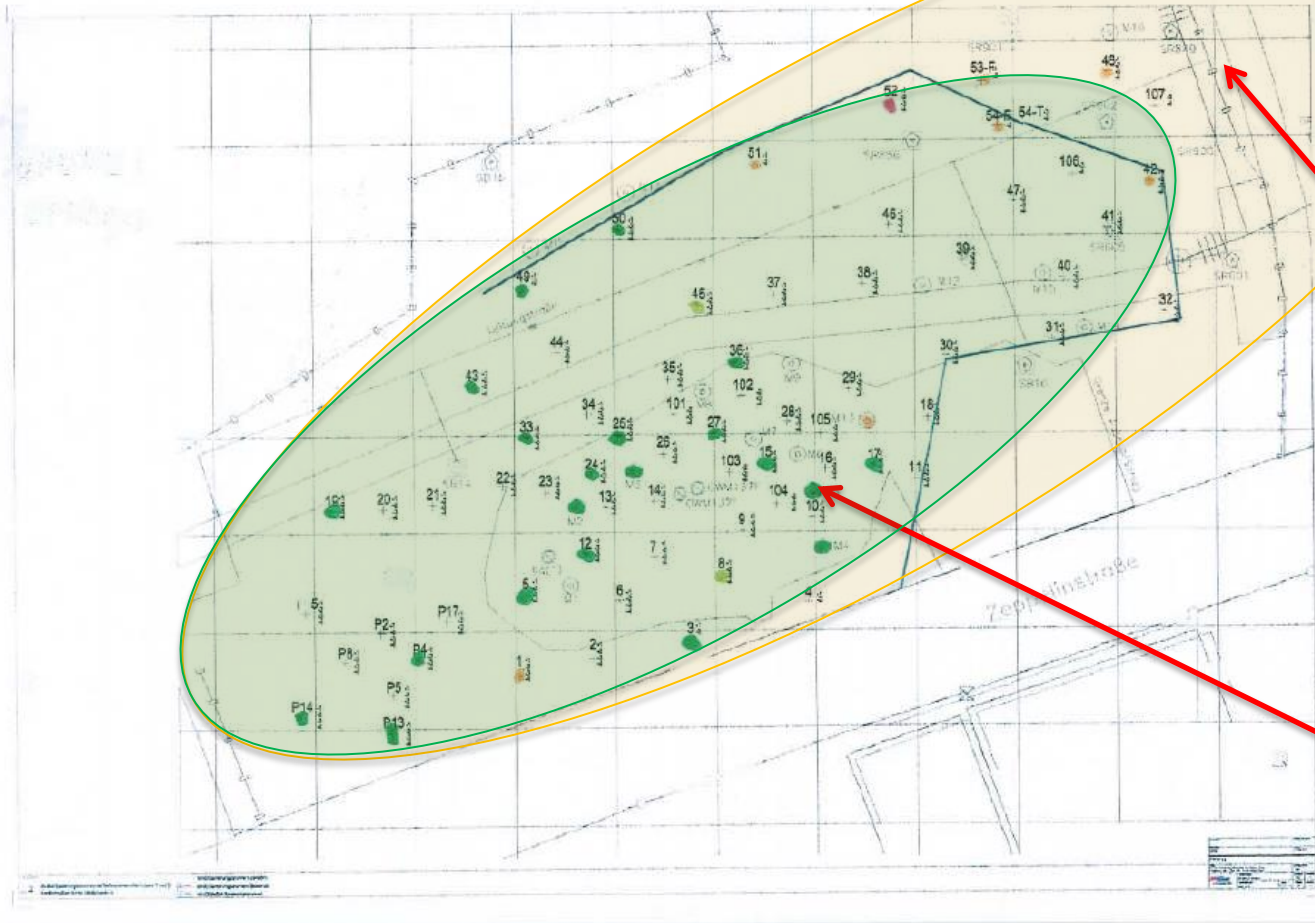
Orange:
1.000-10.000 $\mu\text{g/l}$

Red:
>10.000's $\mu\text{g/l}$

Purple:
>100.000 $\mu\text{g/l}$



Nordhorn - end remediation



**Situation
Summer
2011**

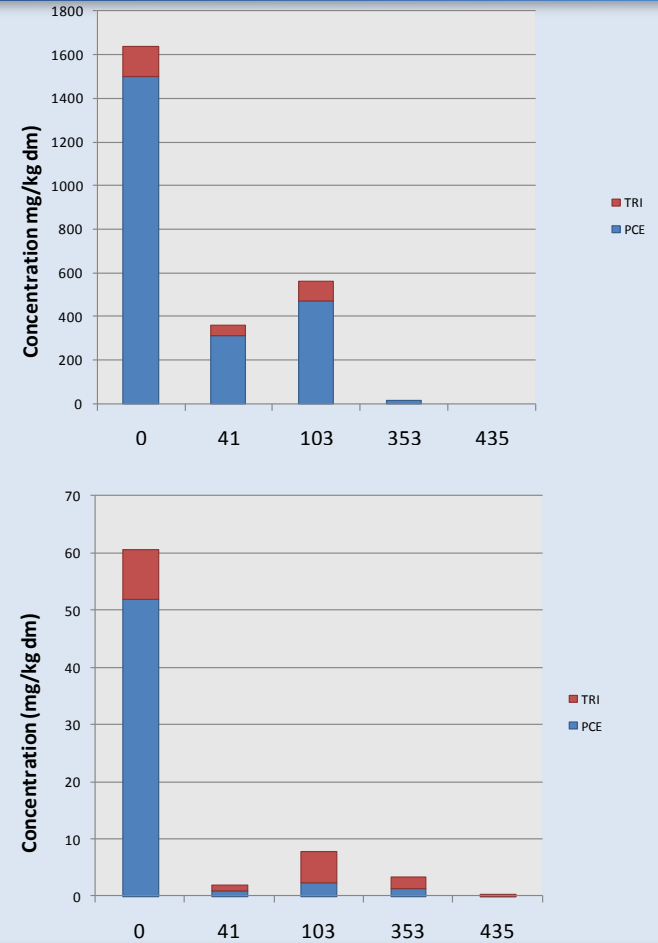
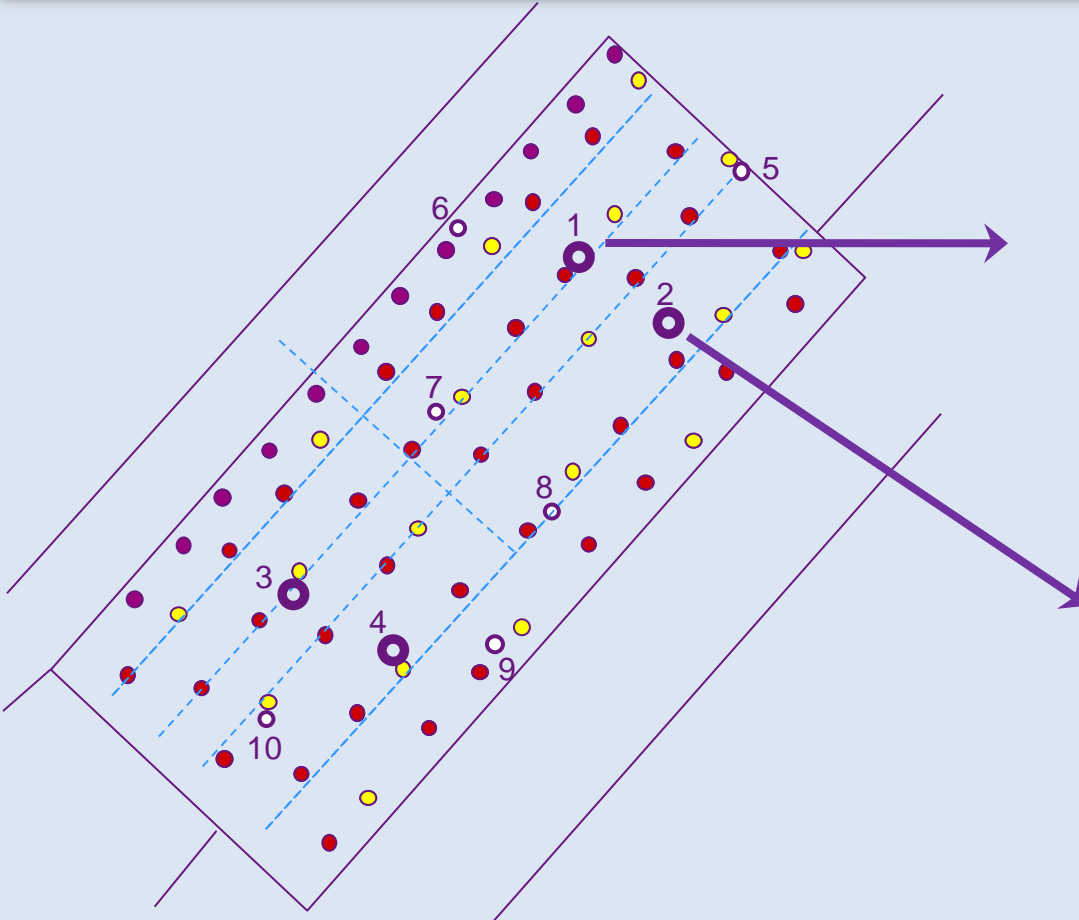
**Downstream
(outside
remediation
area),
concentration
levels above
objective**

**In the original
source area, \leq
50 $\mu\text{g/l}$**

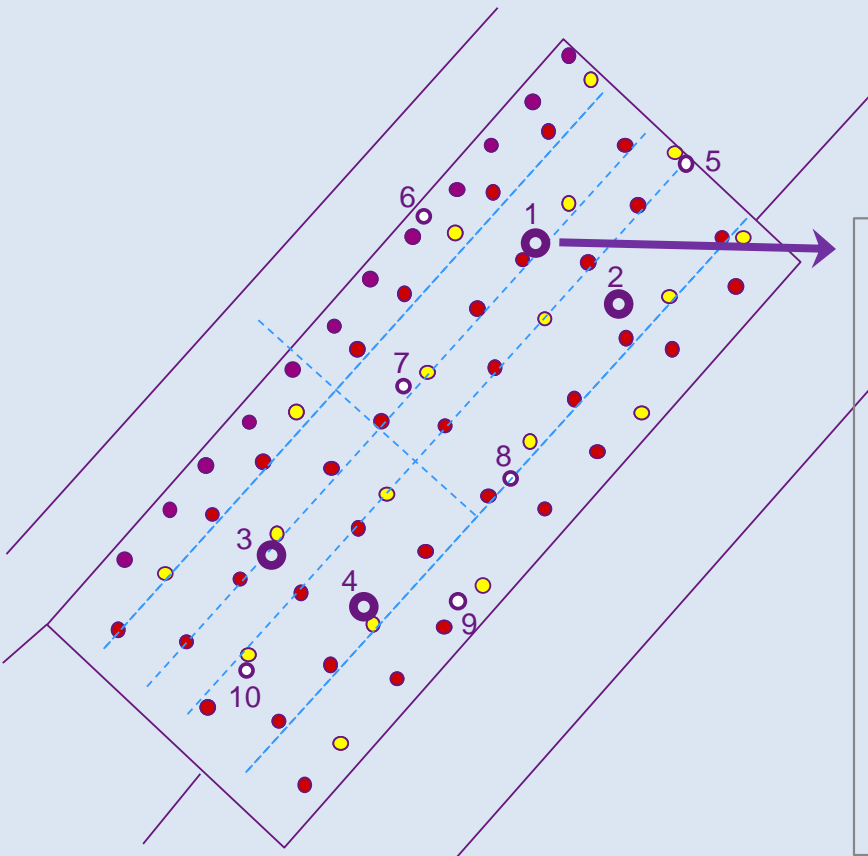
Project Zwanenburg - Pilot set-up (heating)



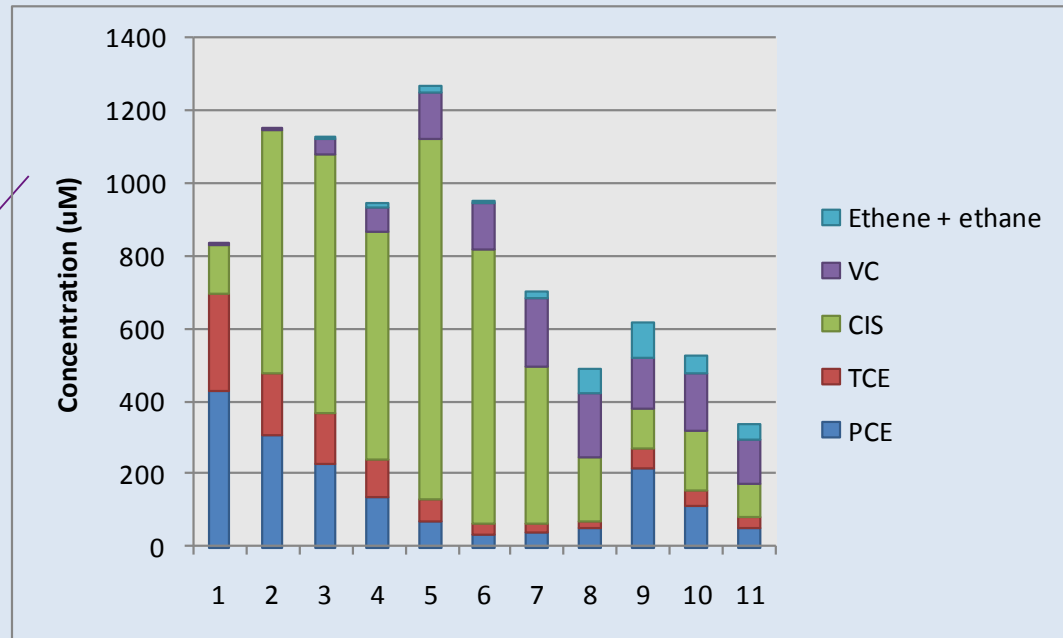
Results heating - soil



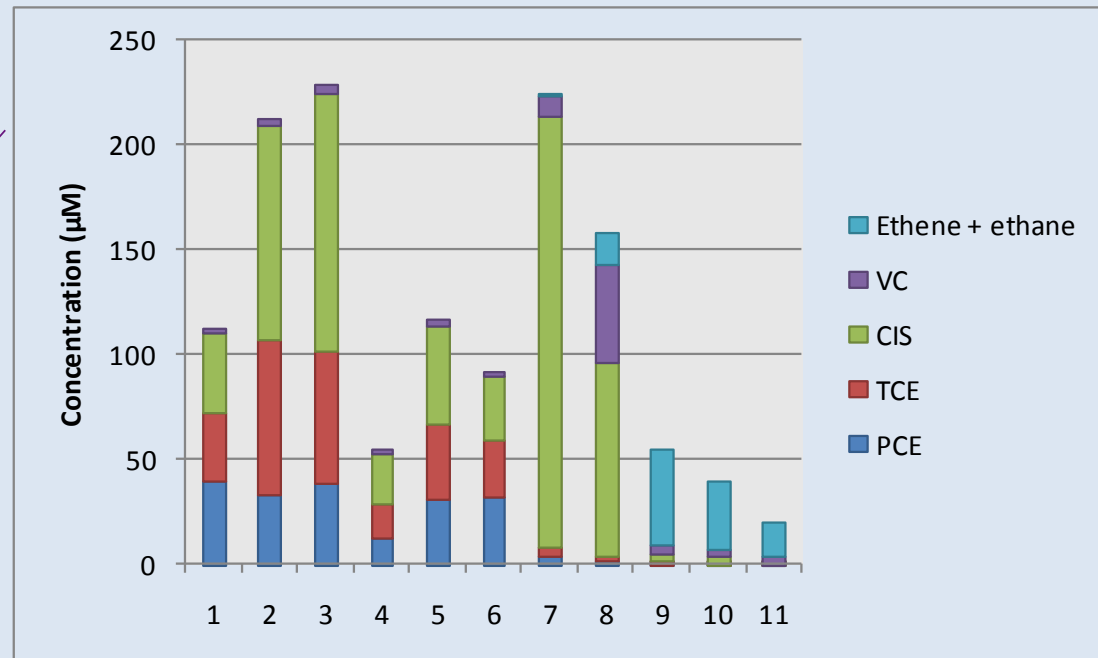
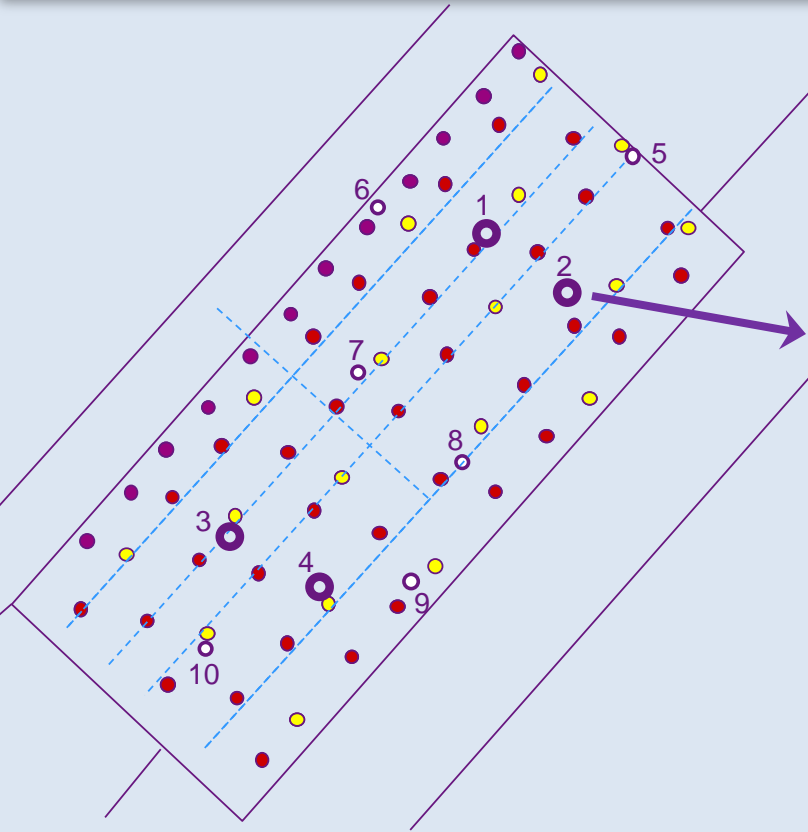
Results heating – ground water



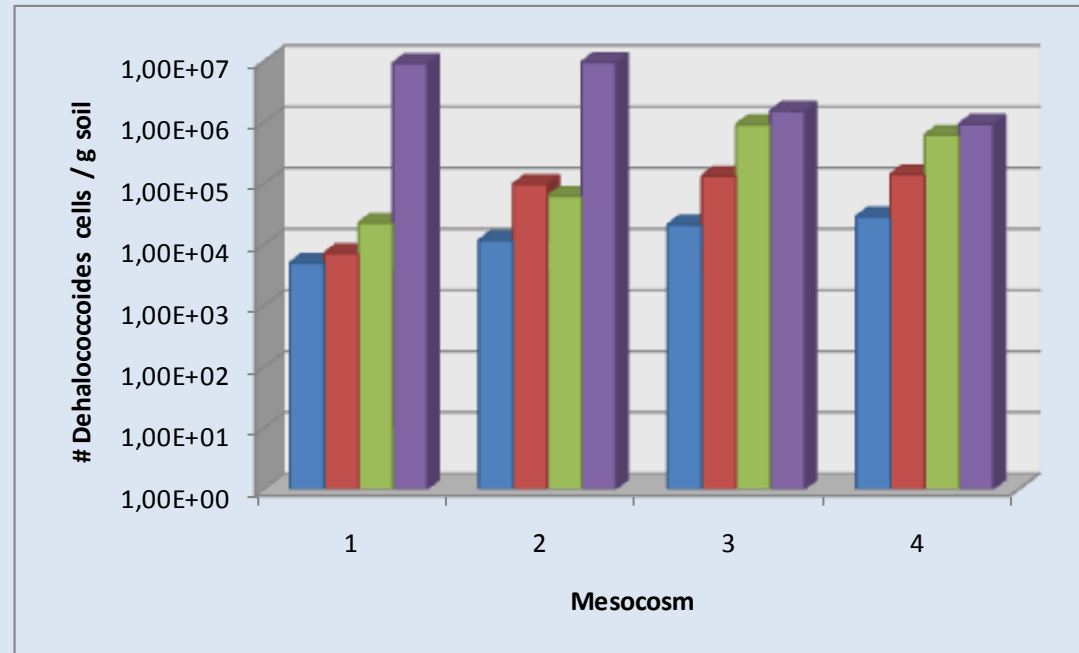
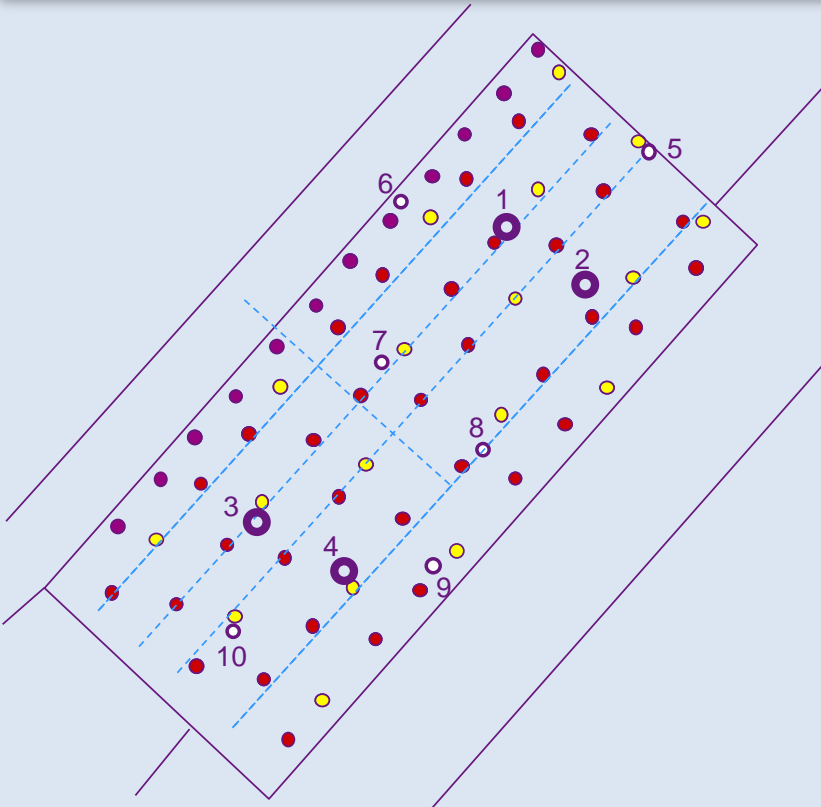
DNAPL present (PCE \pm 27 %
of max. solubility)



Results heating – ground water



Results heating – molecular analyses



Dehalococcoides: CIS/VC \Rightarrow ethene/ethane

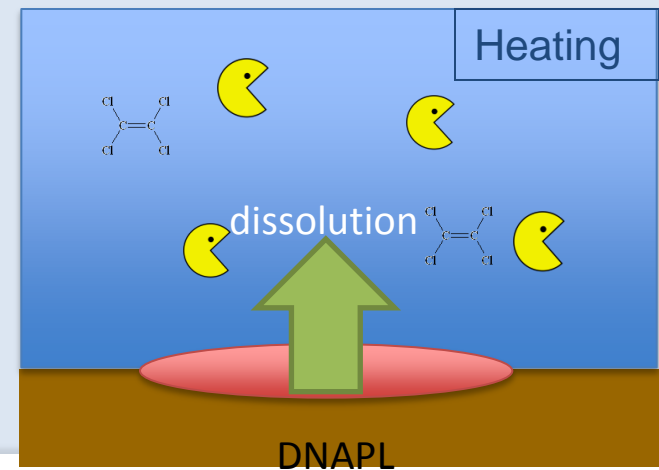
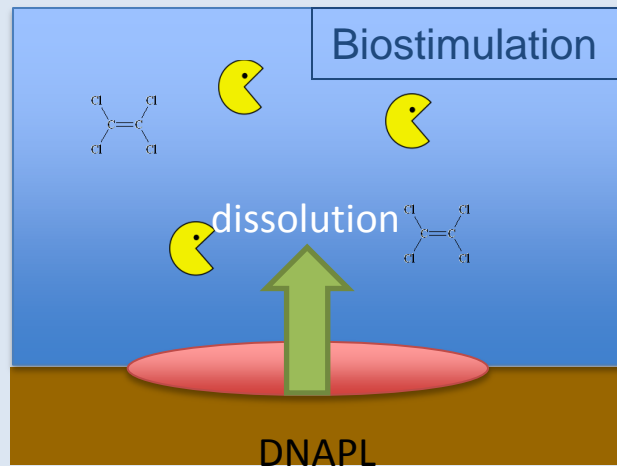
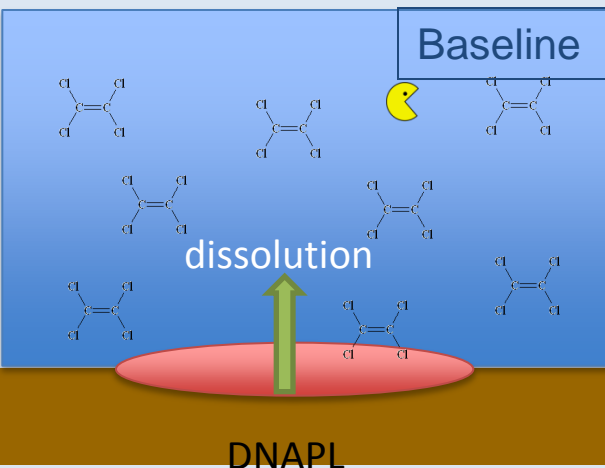
BioSpeed – application

Combination heating + inoculation (BioSpeed)

- “quick start” unit (start on small scale)
- Circulate heated (25° C) groundwater + dose ED in small number of wells (5 – 10)
- Create a stable population of dechlorinating bacteria
- Meanwhile prepare full scale area and optimise redox conditions
- Use water from “quick start” area as inoculum, once the full scale redox conditions are sufficient

Bioenhanced dissolution

Bioenhanced dissolution: up to 16 times



BioSpeed – application



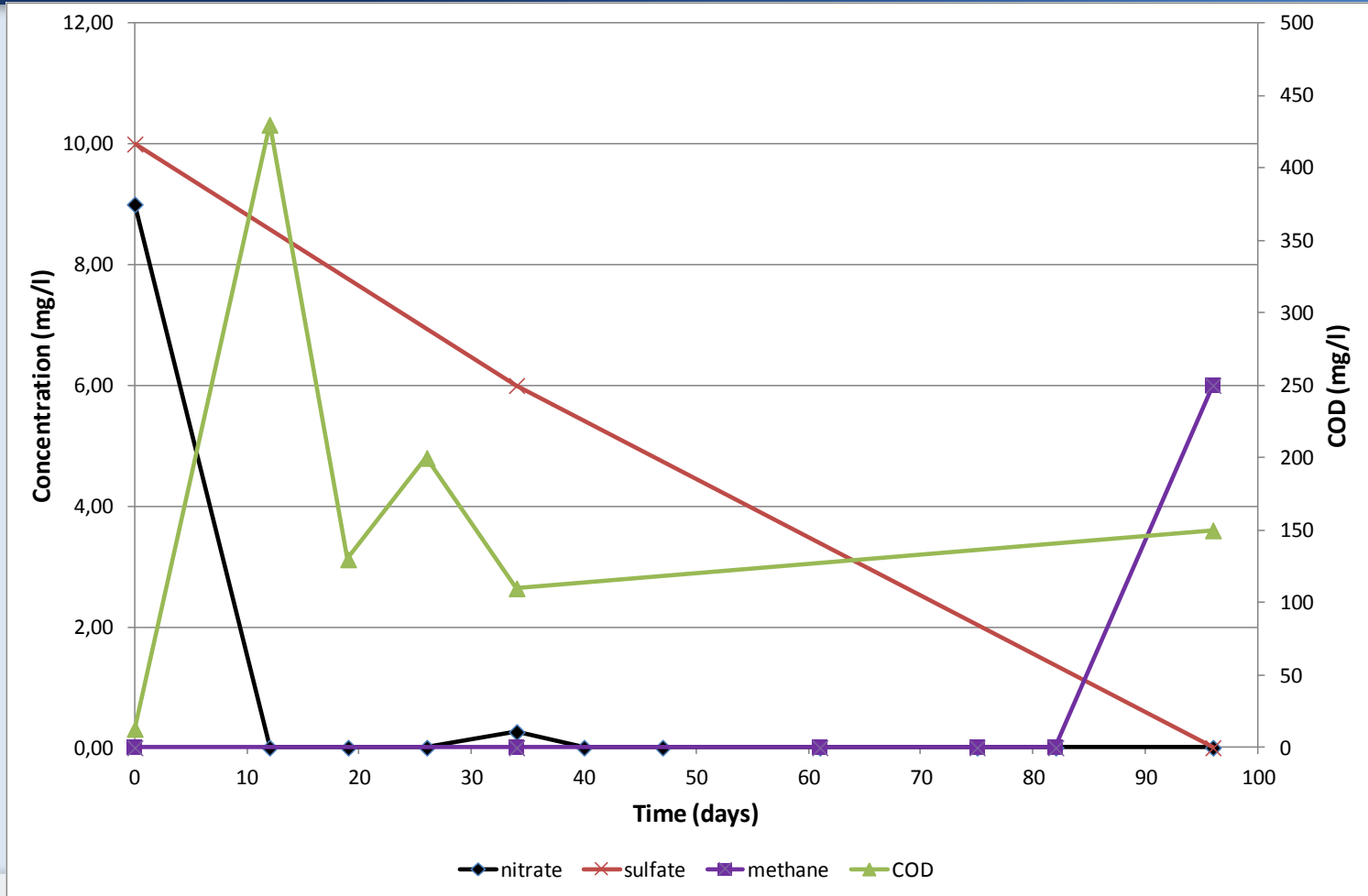
Project characteristics:

- Area $\pm 2,2$ ha
- Polluted with mainly PCE/TCE
- Pre-investigation:
 - only *Dehalococcoides* spp. detected ($2.4 \cdot 10^1$ N/ml) in 2 of the 4 investigated wells.
 - no VC reductase (*vcrA*) found ($< 1.3 \cdot 10^1$ N/ml)
- Predominant redox conditions aerobic
- High NO_3 (up to 38 mg/l)
- No natural electron donor present
- Remediation target: finish within 2 years (sum cVOC = 1000 $\mu\text{g/l}$)

BioSpeed application – “quick start unit”

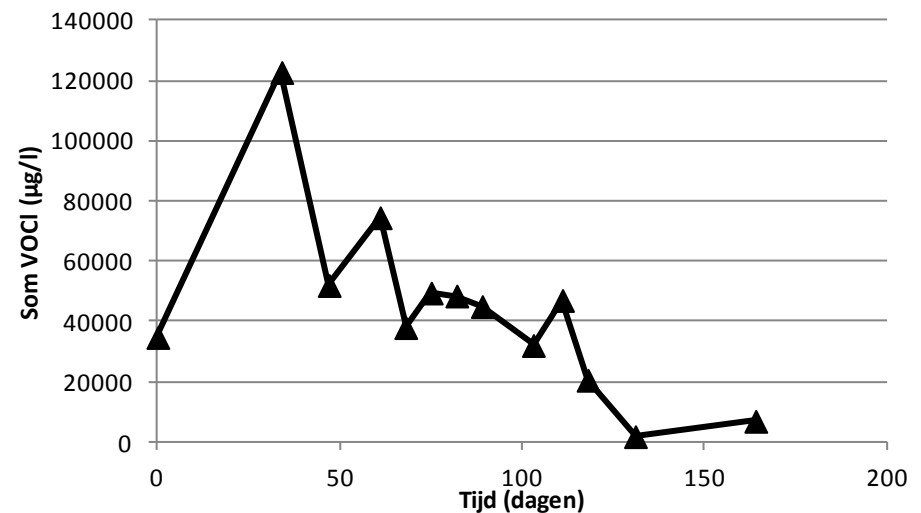
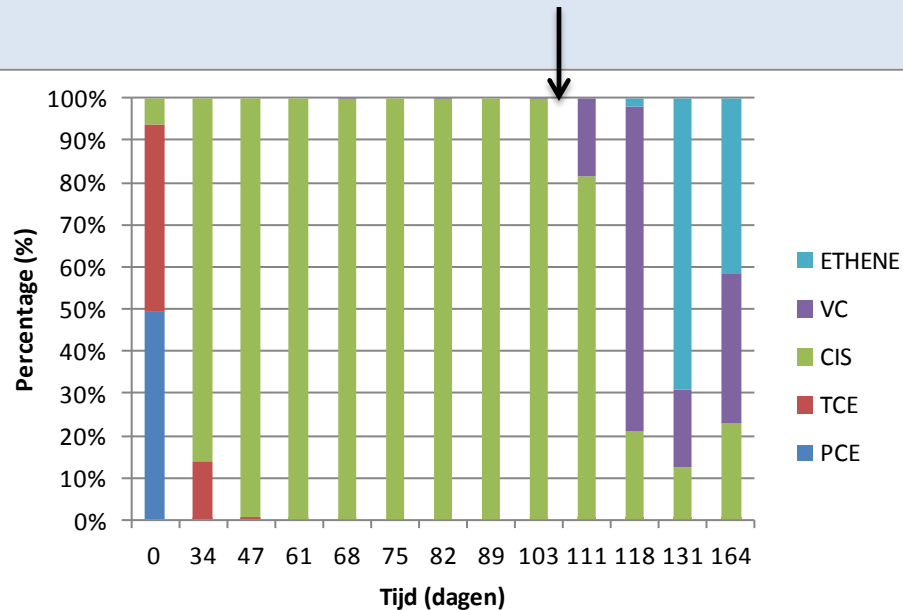


BioSpeed application – redox conditions



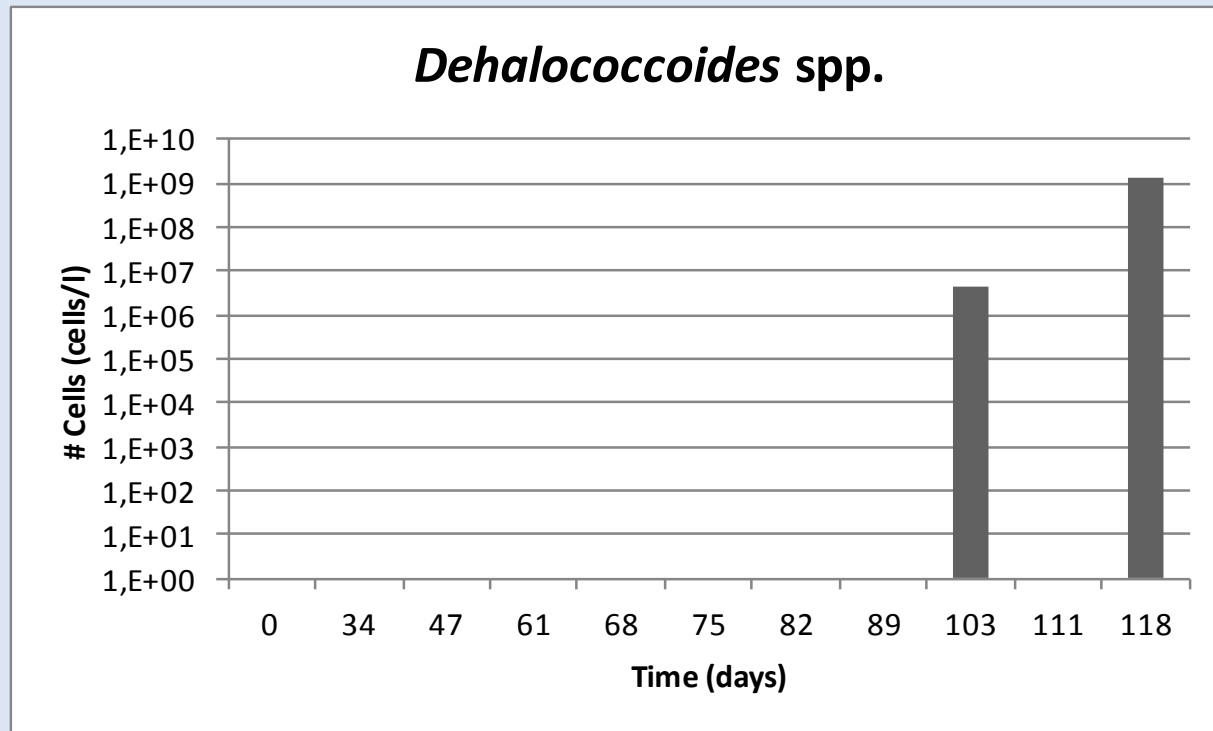
BioSpeed application – cVOC results

Inoculation with ground water from location with Dcoc

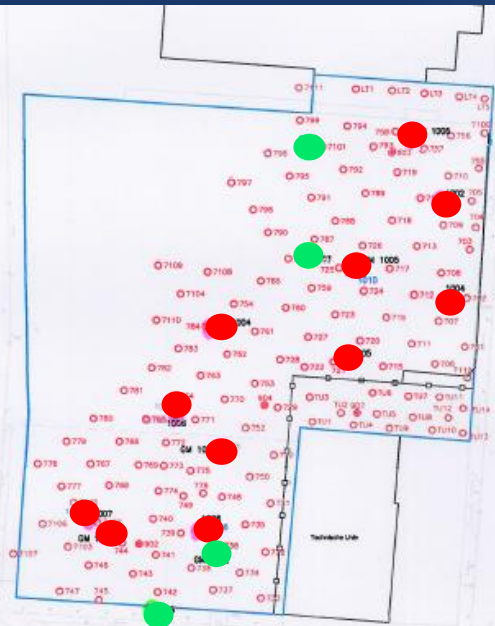


Starting concentrations: PCE and TCE \pm 25,000 µg/l and CIS 2,500 µg/l
CIS production up to 140,000 µg/l

BioSpeed application - # *Dehalococcoides*



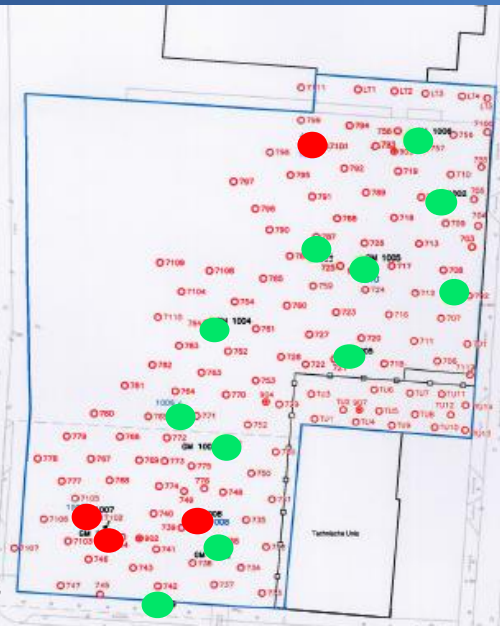
BioSpeed application – Full Scale



September 2012

● > 1000 µg/l

● < 1000 µg/l



Surface
= 2,2 ha

3 wells 2,000-3,000 µg/l
1 well 52,000 µg/l (from 119,000 µg/l)

LEGENDA		Onderwerp		Locatie		Datum		Schied	
Monitoringpeilbuis (8,5 - 7,5 m-nv)	Saneringlocatie	Project	B065 Nijmegen	Gepl.	NND	1:1000			
Onttrekking-infiltratiebuis (4,0 - 7,5 m-nv)	Monitoringpeilbuis bodemlucht (1,5 - 3,0 m-nv)	Opdrachtgever	Deconcrete Nijmegen	Ontw.	3-8-12	A2	1.2		
Onttrekking-infiltratiebuis (8,0 - 9,0 m-nv)									

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Onttrekking-infiltratiebuis (8,0 - 9,0 m-nv)									

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ERD – source zone

Remove source!

- Excavate soil contamination (unsaturated zone)
- Remove DNAPL (special pump)

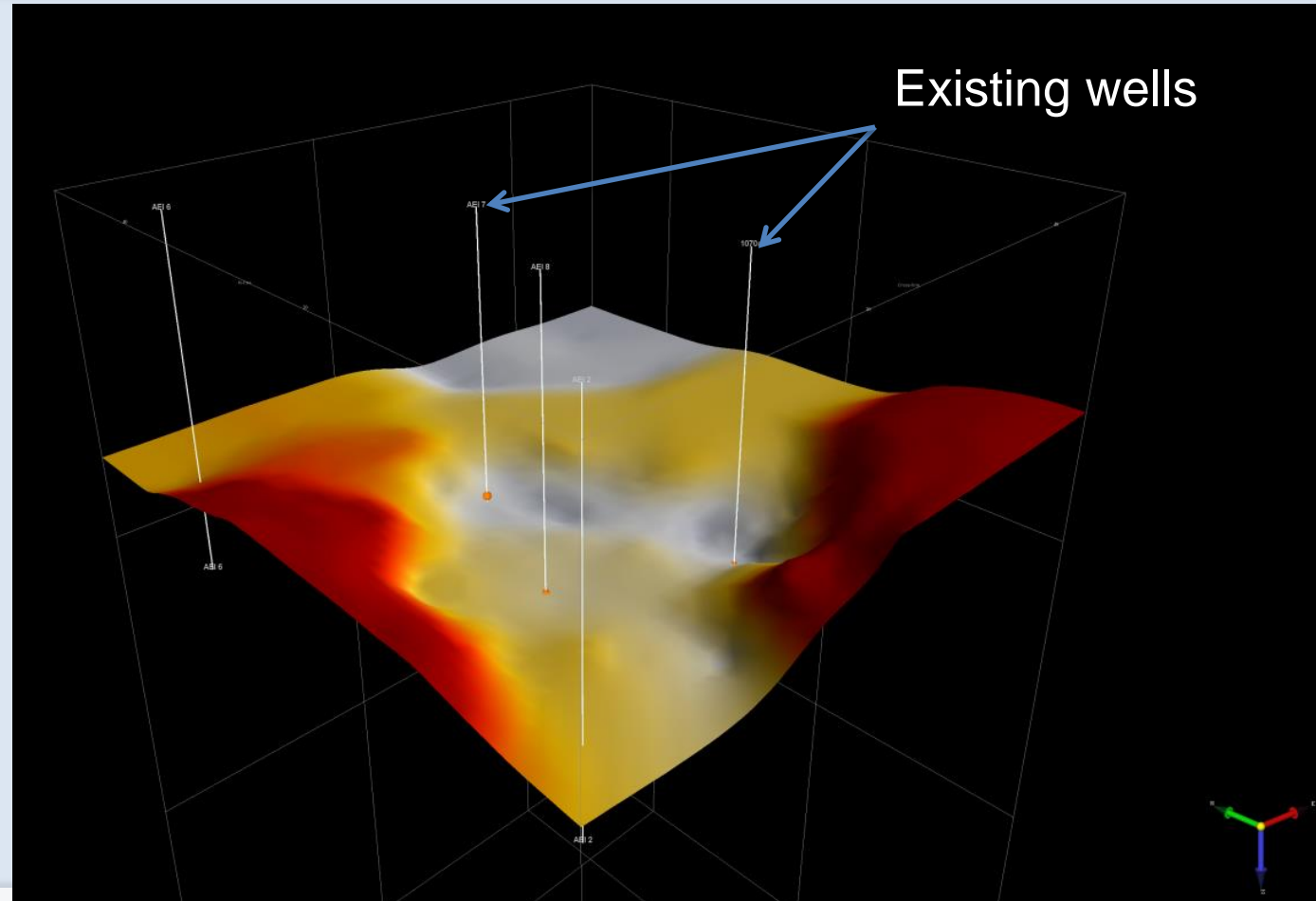
However finding it is a challenge!

<https://www.youtube.com/watch?v=Rk2M9jA0zts>



ERD – source zone

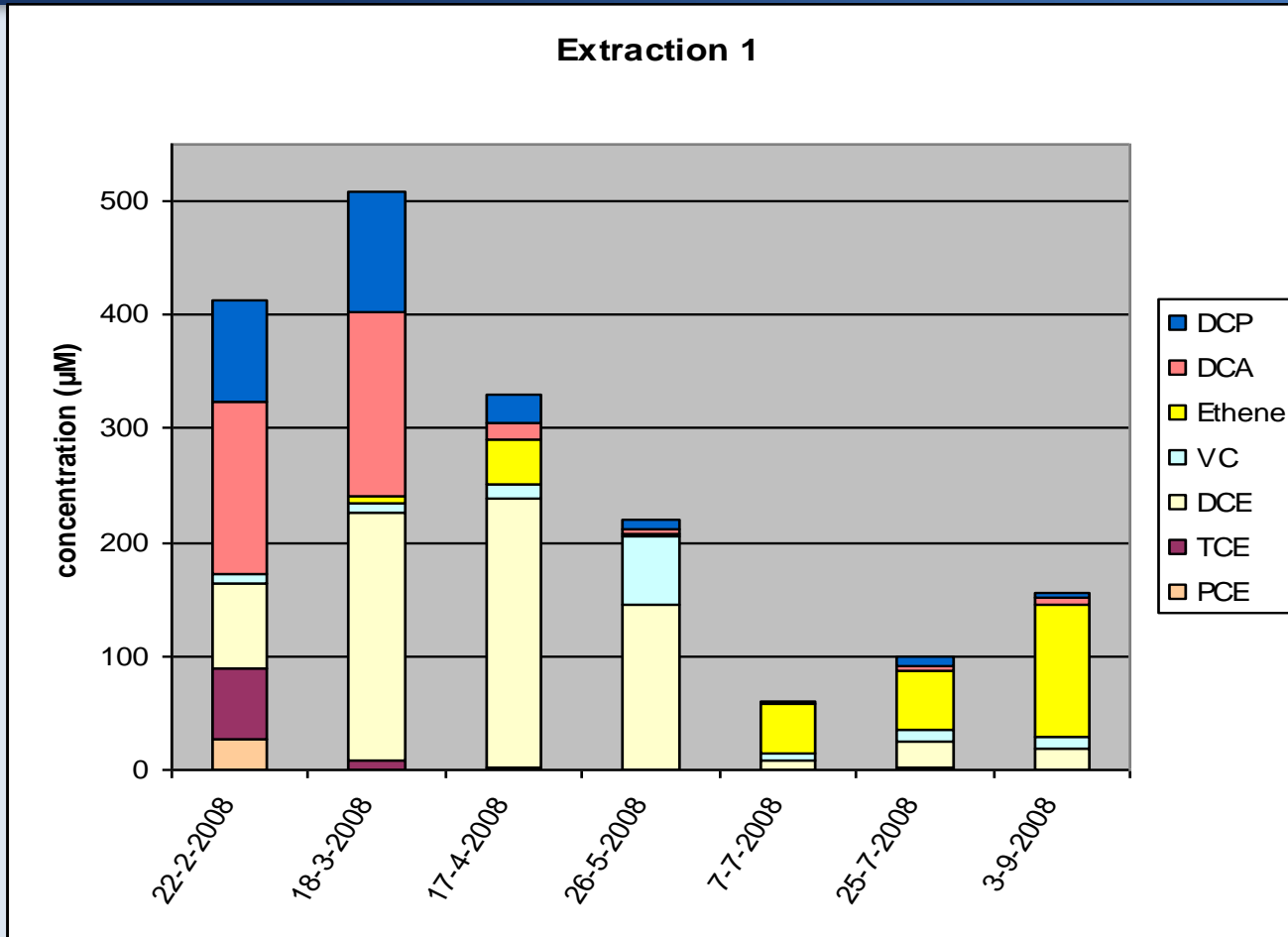
- Based upon results full scale remediation system has been designed
- Level of rock important for free phase removal → **Seismic investigation**



Specials

- Mixture VOCl: chloroethenes, DCP, DCA (Cassinetta, Italy)
- Trichlorobenzene (anaerobic TCB \rightarrow DCB/MCB; aerobic DCB/MCB \rightarrow CO₂)
- Bioreactor for removal PCE/TCE (anaerobic PCE/TCE \rightarrow CIS; aerobic CIS \rightarrow CO₂)
- DCA (Wales, Finland)
- Anaerobic landfarming/biopiles (Eindhoven)
- Anaerobic biobarrier

Cassinetta, Italy



Biological degradation – ground water treatment

Anaerobic

PCE



CIS

↑
Percol

Aerobic (co-metabolic)



$\text{CO}_2 + \text{H}_2\text{O}$

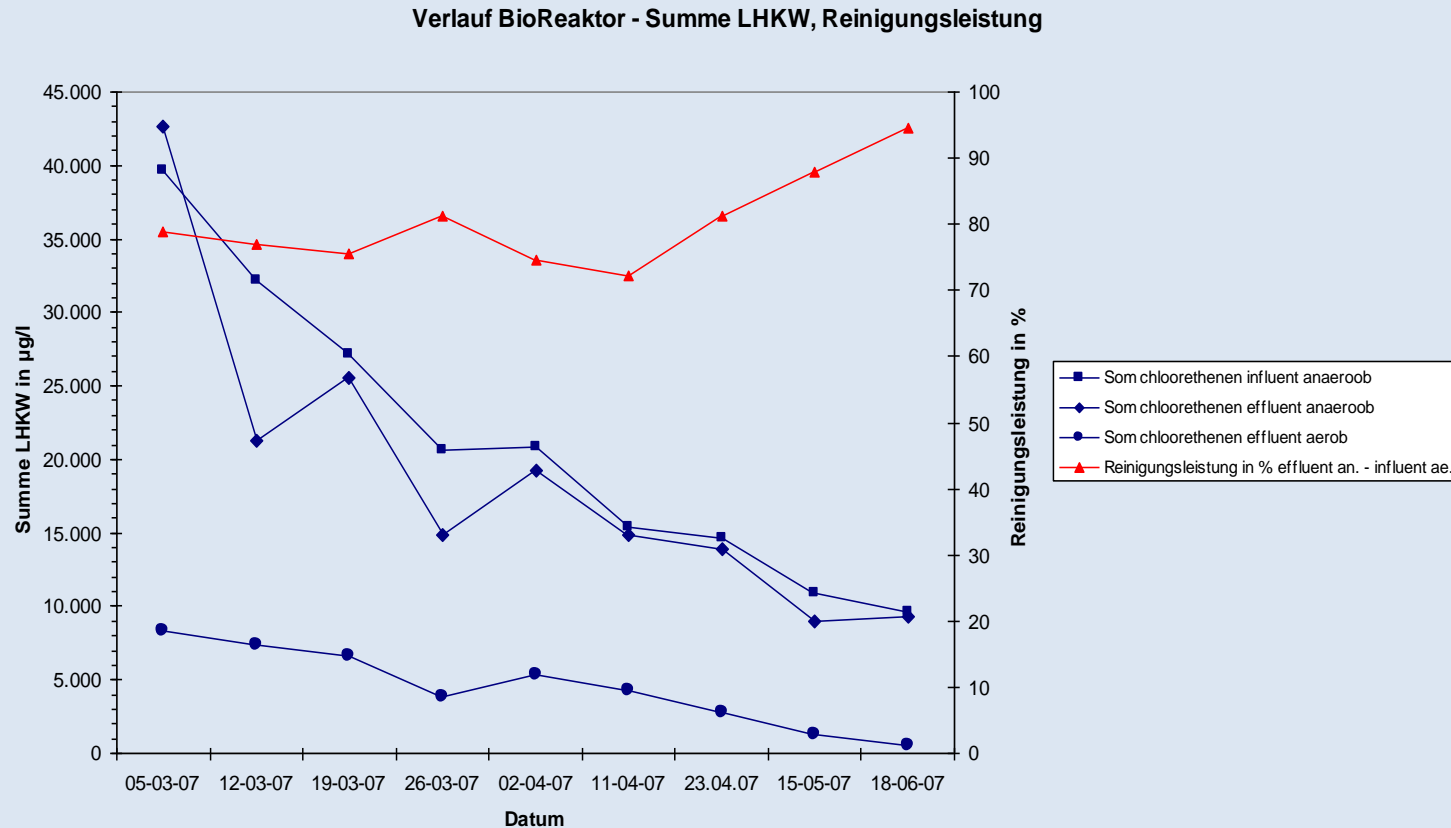
↑
Butane + O_2 + N/P

HRT = 4 hours

Biological degradation – ground water treatment

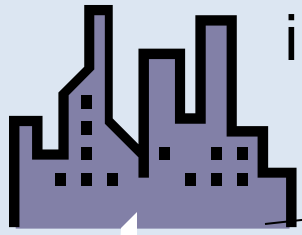


Biological degradation – ground water treatment



Bioscherm

industry

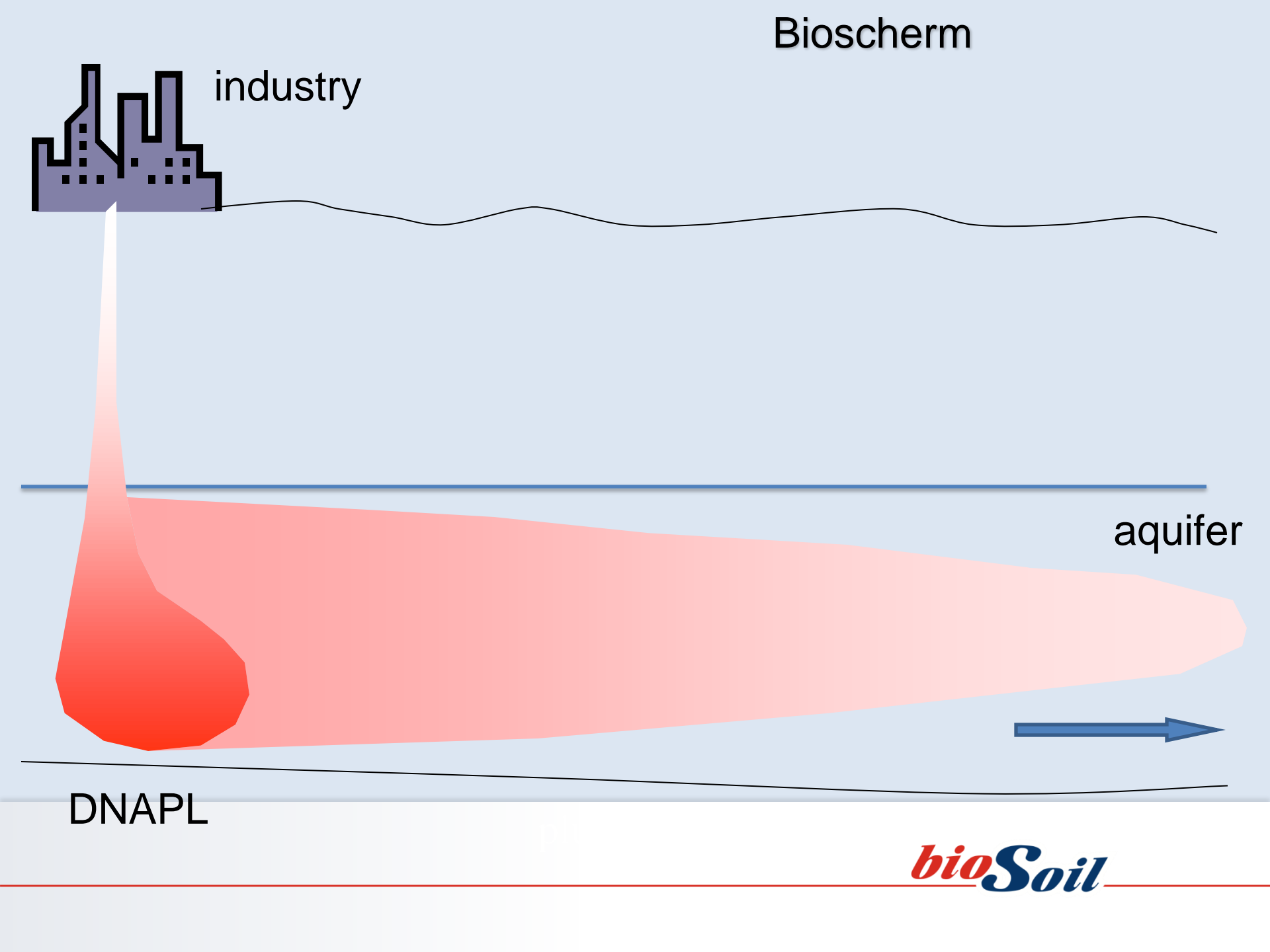


aquifer



DNAPL

*bio*Soil



Bioscherm

industry

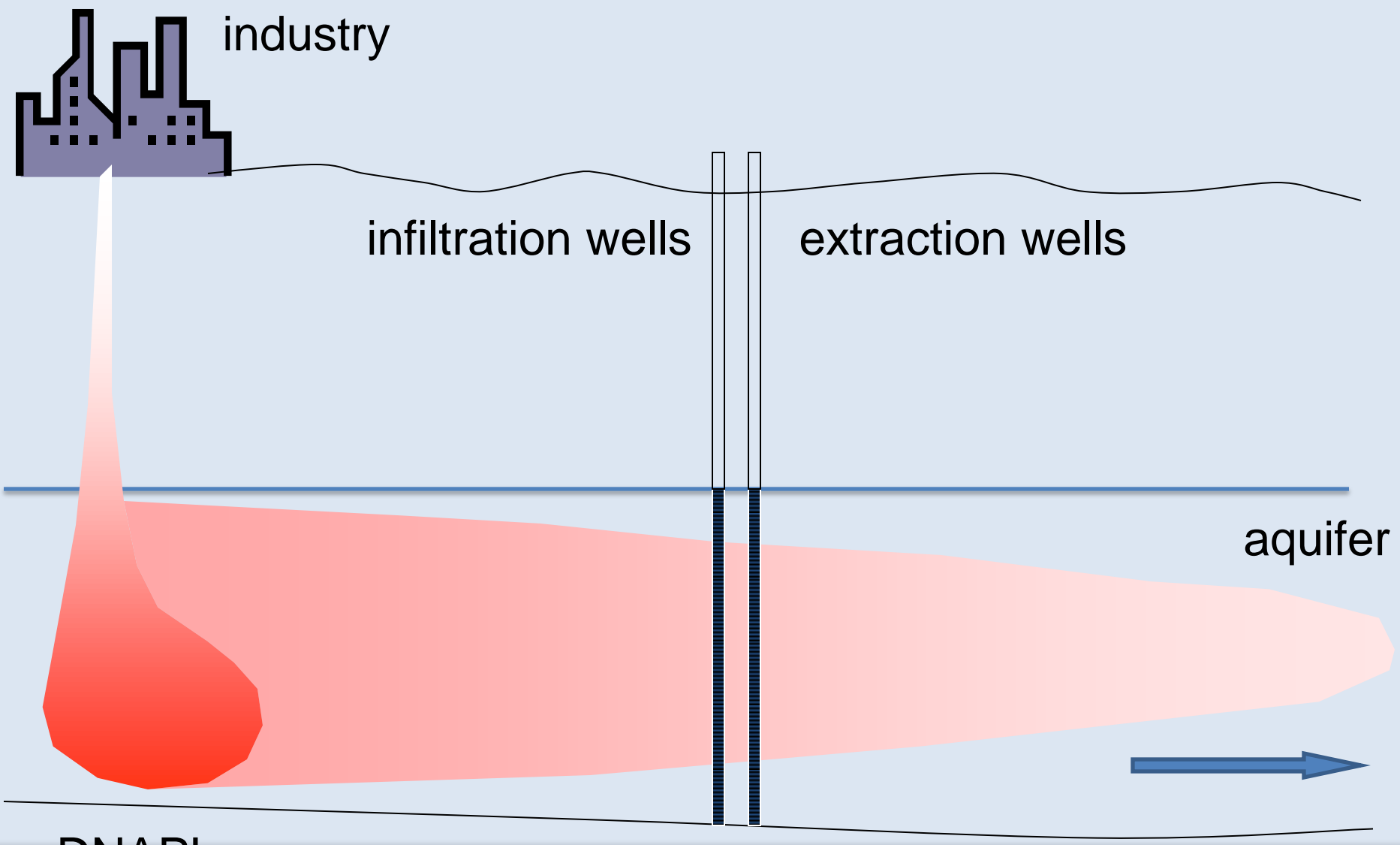
infiltration wells

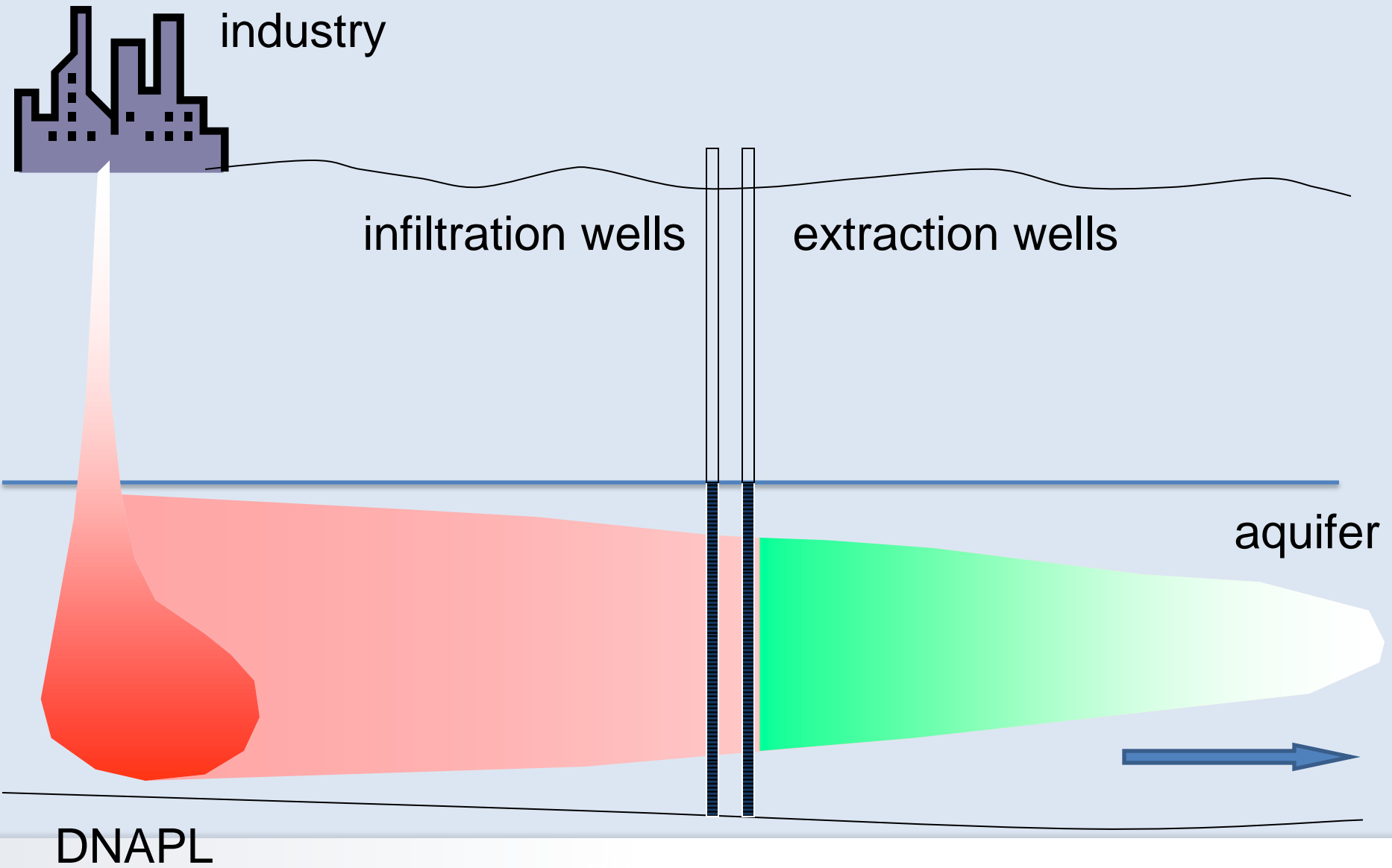
extraction wells

aquifer

DNAPL

*bio*Soil





DNAPL

Conclusions

- cVOC can degraded biologically (mainly anaerobically)
- ERD is based on stimulation by adding C/E-source
- Preceed full-scale remediation with pilot (and use as source of inoculum) can reduce the start-up phase significantly
- Also combination possible of anaerobic-aerobic
- ERD is an efficient and sustainable bioremediation technique for cVOC

Thank you for your attention!