Ten years of experience with the new TCE-concept for bioaugmentation in full-scale applications

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Spring meeting 13-14 April 2011, Sundsvall, Sweden

Presentation

- Introduction:
  What is bioremediation and why need for bioaugmentation?
- History of the TCE-concept and the first application….
- Experiences in various cases
- Conclusions

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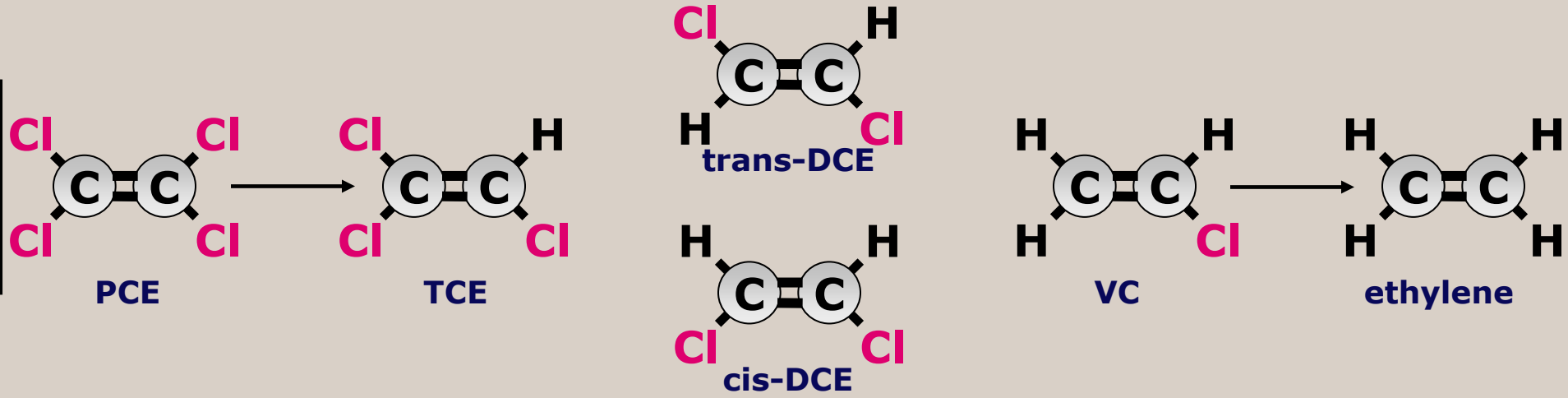
What is bioremediation and why bioaugmentation?

- sufficient electron donor (feed to bacteria for VOC degradation)
- suitable redox conditions (reduced environment) and pH
- presence of suitable microorganisms (*Dehalococcoides*)



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Bio-augmentation

"the introduction of microorganisms into contaminated media to promote degradation"

"Emerging technology" for treatment of groundwater plumes and possibly DNAPLs with chlorinated solvents"

ESTCP, October 2005

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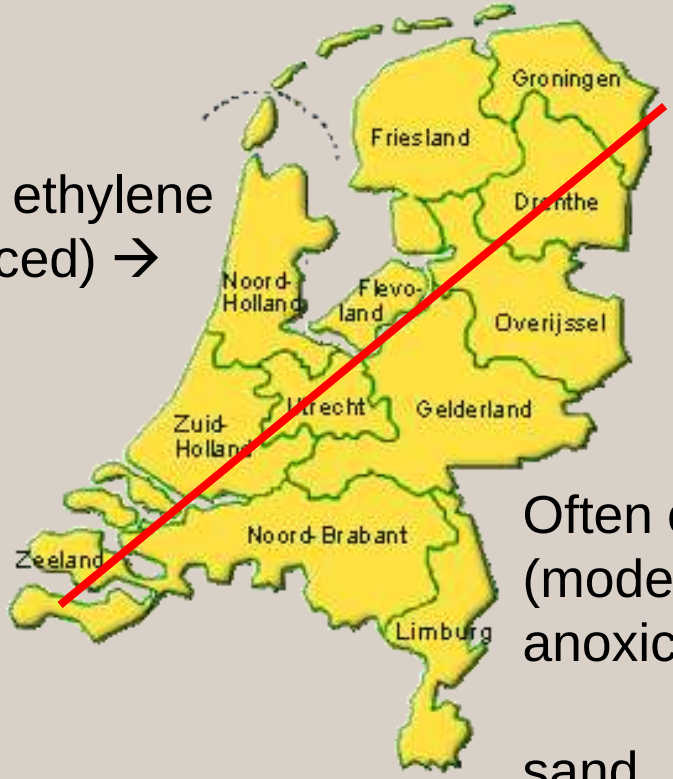
History of TCE-concept

Column experiments 1996-1998

PCE -> ethylene (99%)

Natural attenuation in the Netherlands

Often ethylene (reduced) → DHC



Often c-DCE (moderate reduced, anoxic) → no DHC

sand

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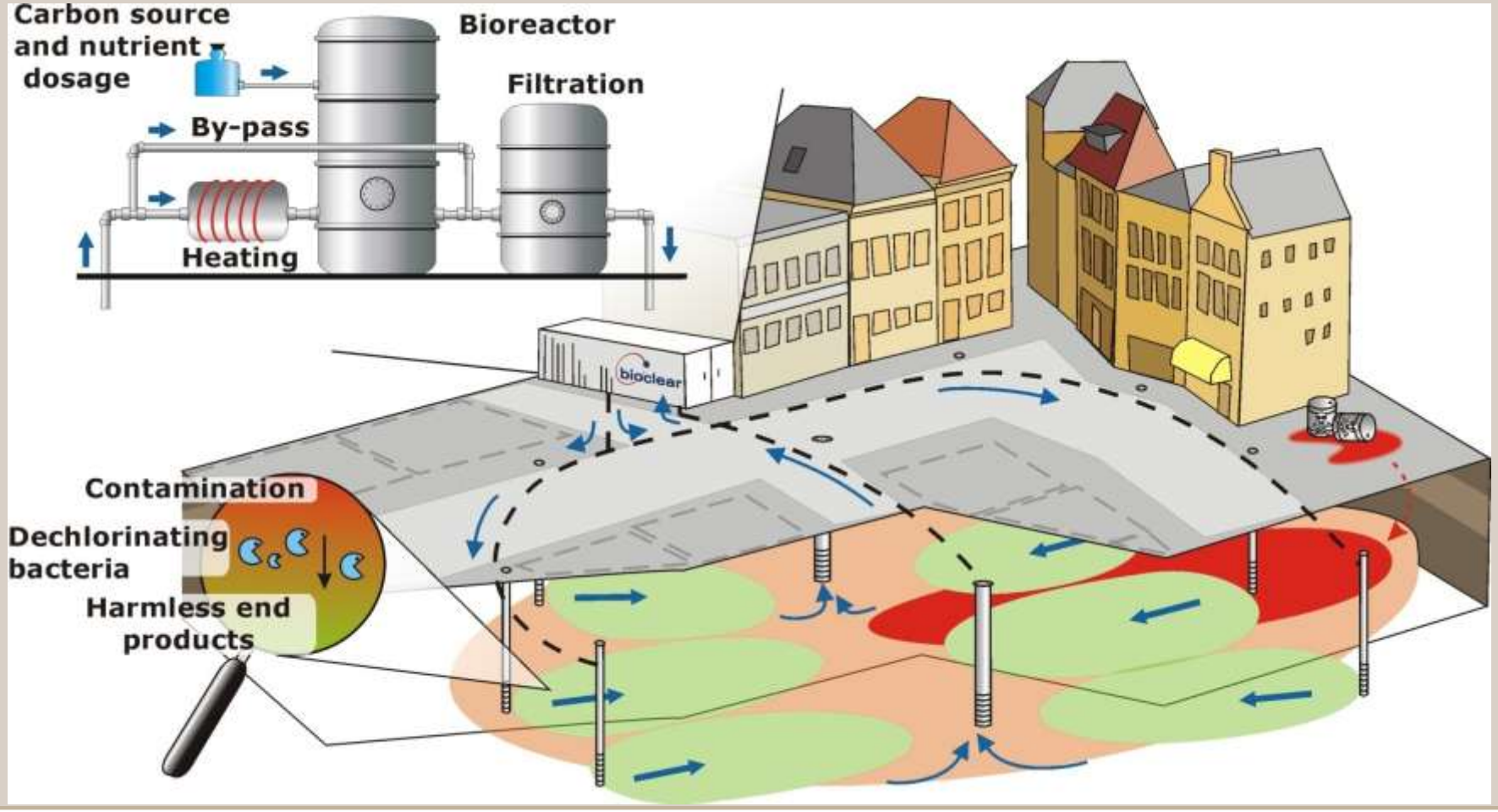
TCE-concept



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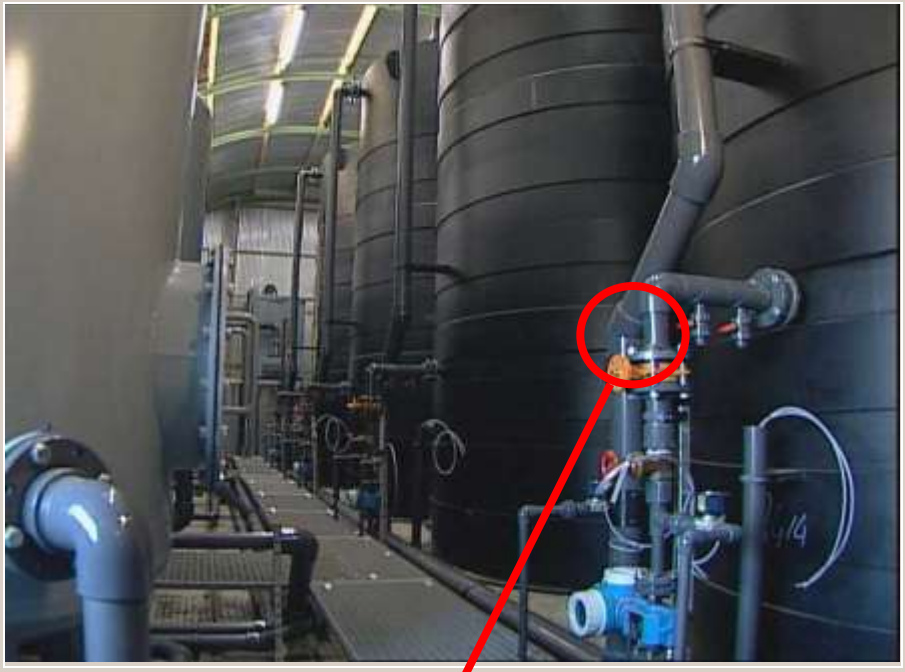
History of TCE-concept

Column experiments, 1996-1998

PCE -> ethylene (99%)

Full scale 100 m^3 bioreactor, 2000



Effluent bioreactor

- PCE to ethylene in 28 days
- Effluent: ≈10^5 cells/ml

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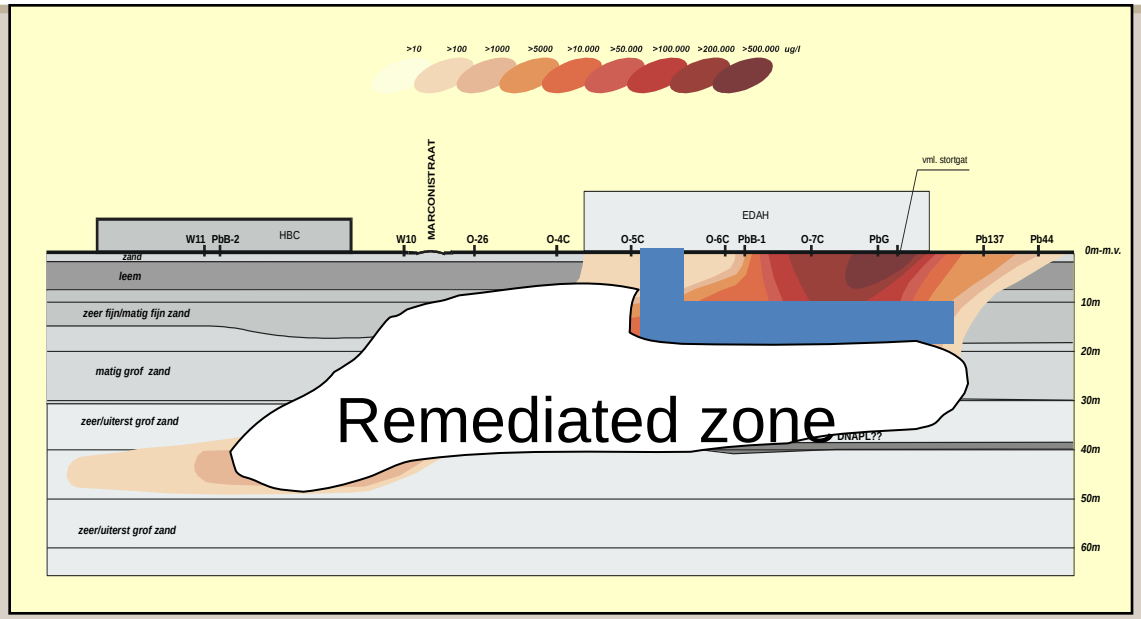
…..and full scale application (2000)



- plume remediation (400,000 m^3, up to 50,000 µg/l PCE)
- successfully remediated, total VOC < 10 µg/l
- more than 98% degradation within 9 months
- core zone stimulation by injection of suitable electron donor (2011)
- augmented organisms still active (4 years after end of active remediation)

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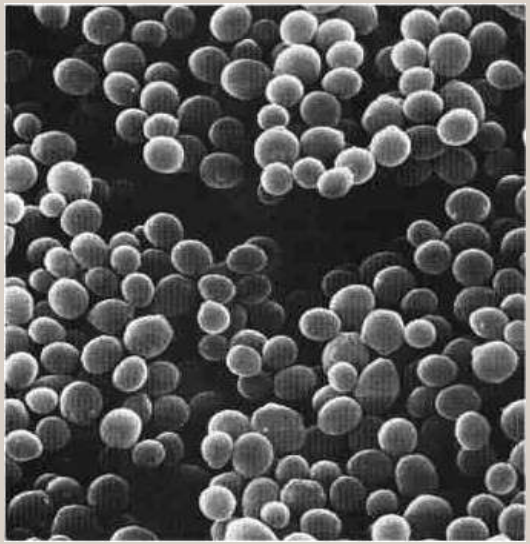
…..and full scale application (2000)

- Monitoring tools developed at own laboratory (2001)
- Using modern DNA-based / PCR analyses, quantitative (q-PCR)
- Follow augmented organisms in treated zone, spreading of organisms after injection and growth

Specific DNA



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…..and full scale application (2003)

Fixed system,
100 m^3 reactor

- mobile anaerobic bioreactor
- automated dosing unit C, N & P
- treatment of effluent bioreactor before infiltration
- ‘plug and play’

Systeem: Logisticon Watertreatment

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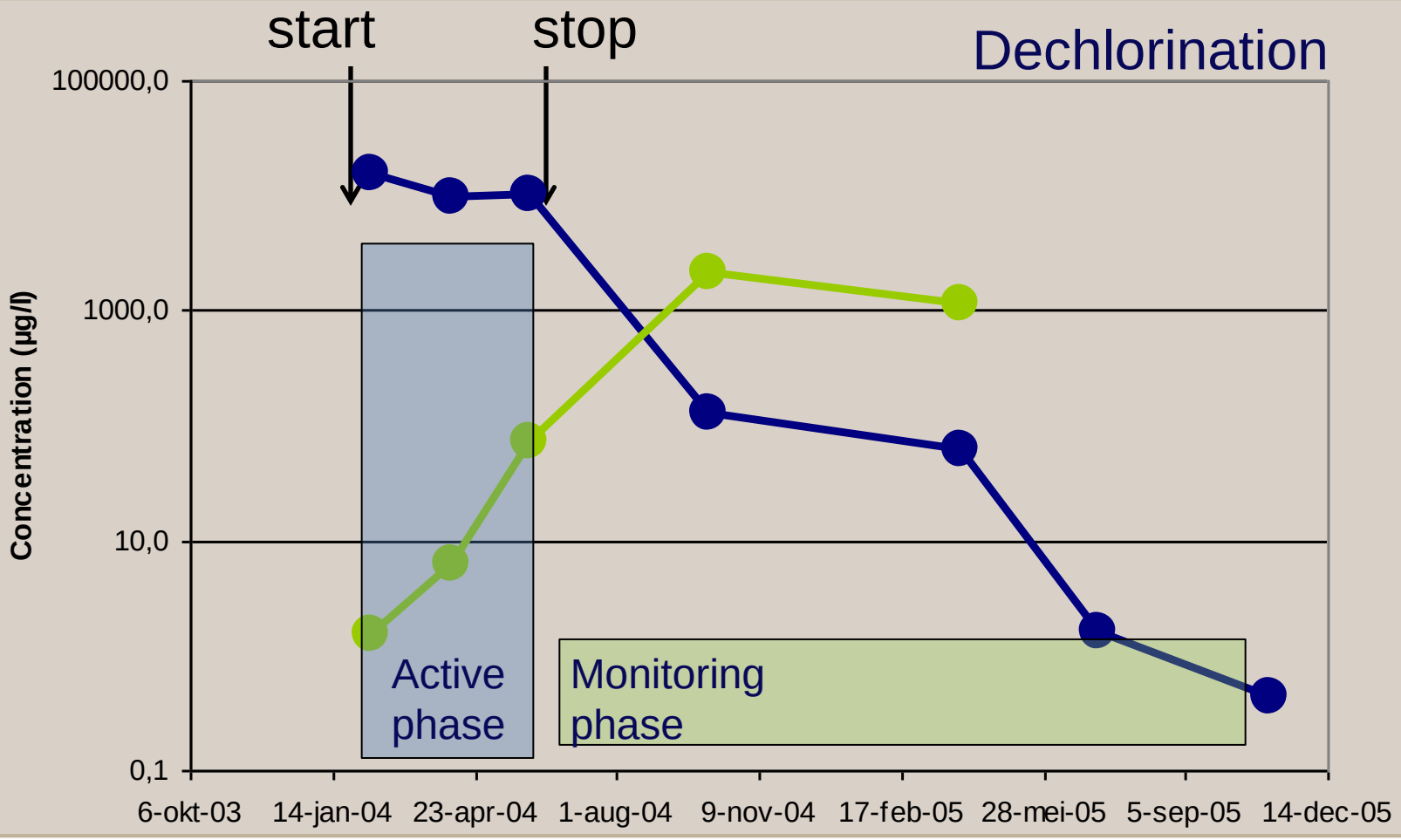
Experiences in various cases (2003-2010)

Almelo site

- former chemical laundry
- ‘residual’ PCE contamination after air sparging
- plume of approx. 12,000 m^3
- PCE up to 15,000 µg/l
- no *Dehalococcoides* present,
  no Natural Attenuation (only PCE)

Almelo site



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Almelo site

Concentrations contamination and degradation products

	10 February 2004	8 April 2004	2 June 2004	5 October 2004	31 March 2005	7 July 2005	3 November 2005
PCE	15,000	7,000	< 0,1	0.2	< 0.1	< 0.1	< 0.1
TCE	< 40	1,300	< 0,1	< 0.1	< 0.1	< 0.1	< 0.1
cis-DCE	< 40	1,300	10,000	45	33	0.76	0.30
VC	< 40	n.a.	n.a.	23	27	0.80	0.13
Ethylene	0.2	4	58	2,100	680	n.a.	n.a.
Ethane	1.3	2	13	6	470	n.a.	n.a.

- 4 months active treatment, 13 months monitoring
- remediation to levels below 1 µg/l
- € 13 per m^3 soil volume

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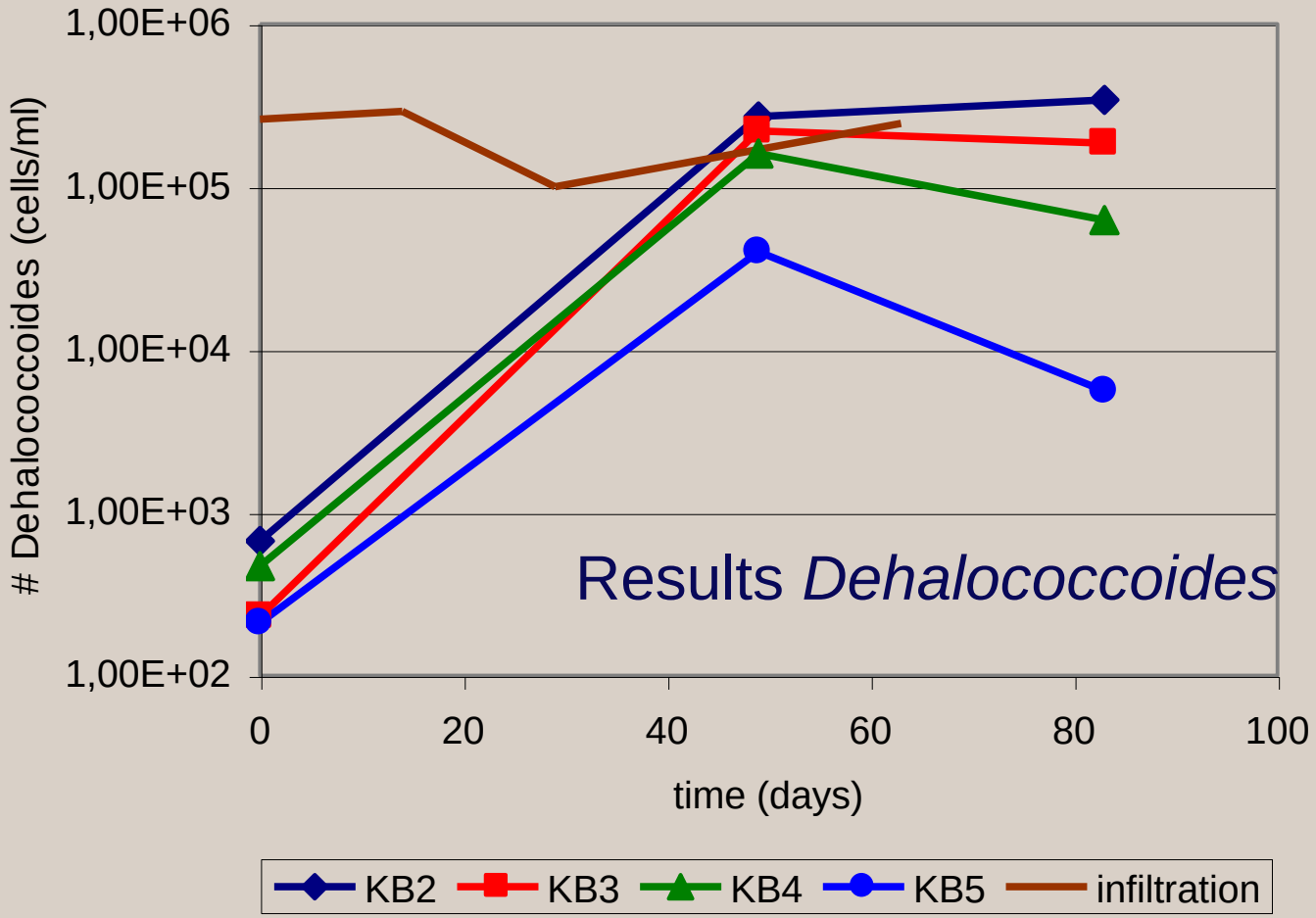
Gl. Kongevej, Copenhagen

- former chemical laundry
- source in clayey till, no reasonable remediation possibilities
- groundwater contamination in limestone aquifer (tenths µg/l)
- plume approx. 2,350 m^3
- TCE as long-term containment method

Gl. Kongevej, Copenhagen



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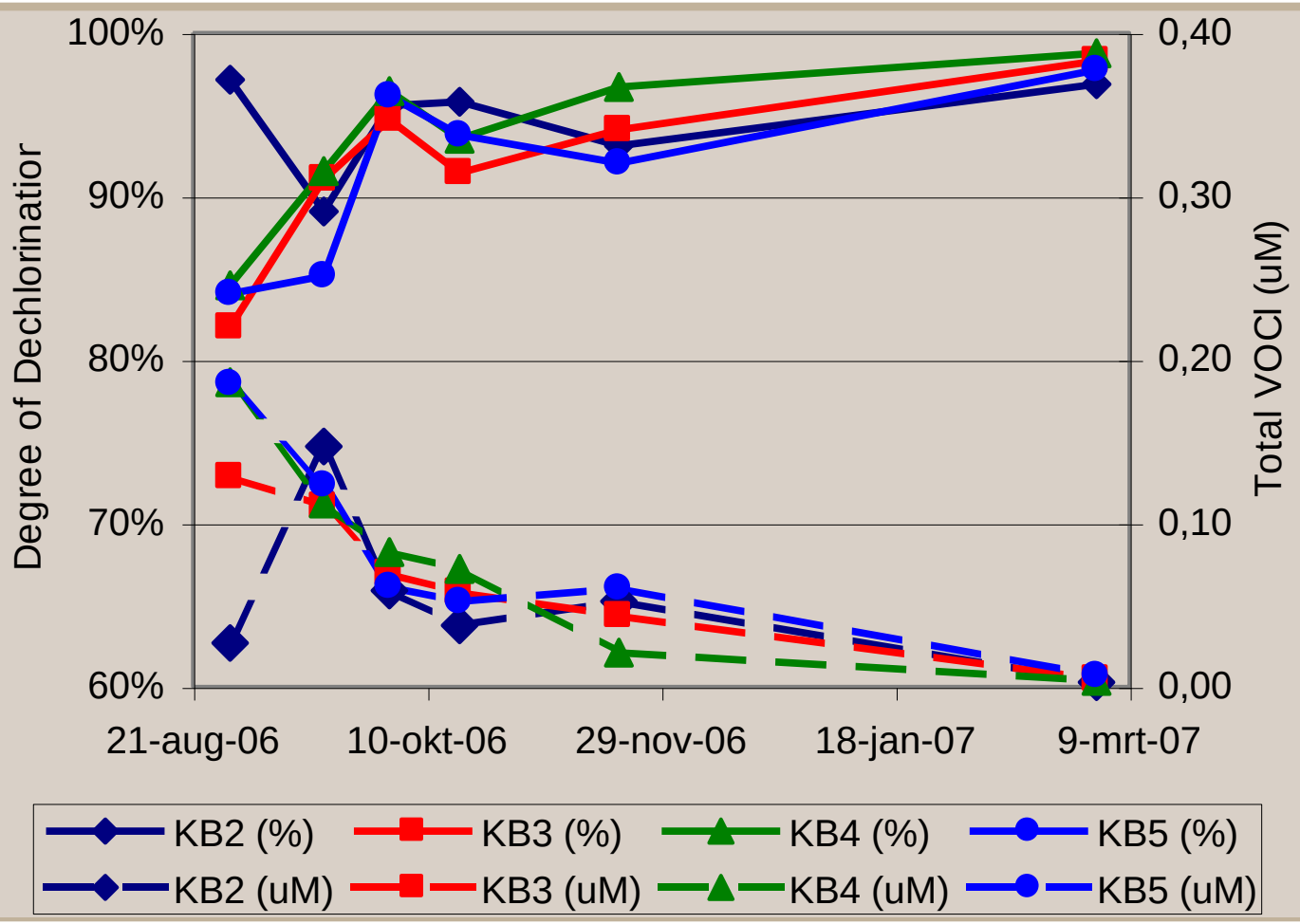

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- active period from 1st September to 27th November 2006 (as planned)
- sulphate completely reduced
- even distribution of TOC and *Dehalococcoides ethenogenes*
- complete degradation in limestone aquifer (< 0,5 µg/l)

active barrier created:
addition of substrate every 1 to 1,5 years

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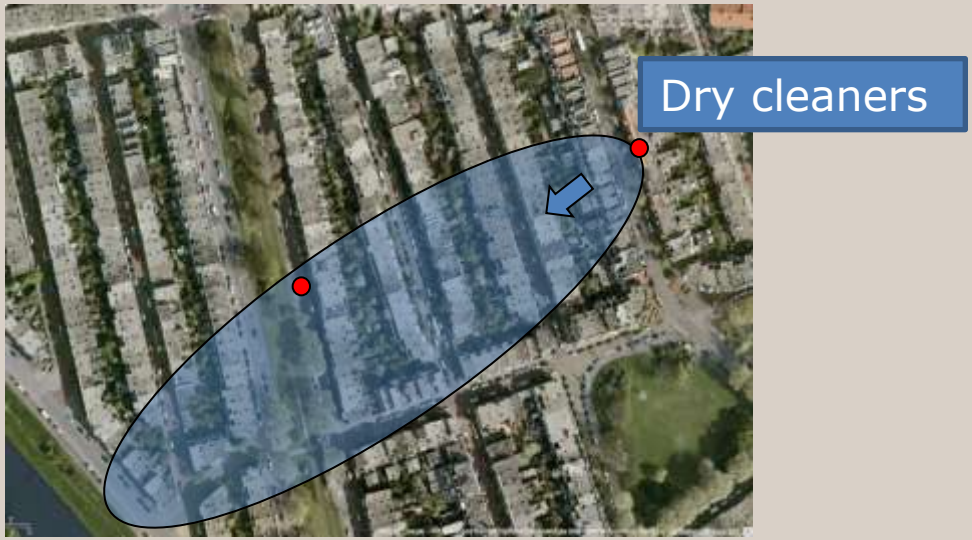
Boreelstraat The Hague

- VOC contamination due to 2 dry cleaners
- Contamination down to 15 m-gl, sandy soil
- Inner city, builded area The Hague
- Contractor NTP
- Remediation 2009-2010
- Volume approx. 400,000 m^3



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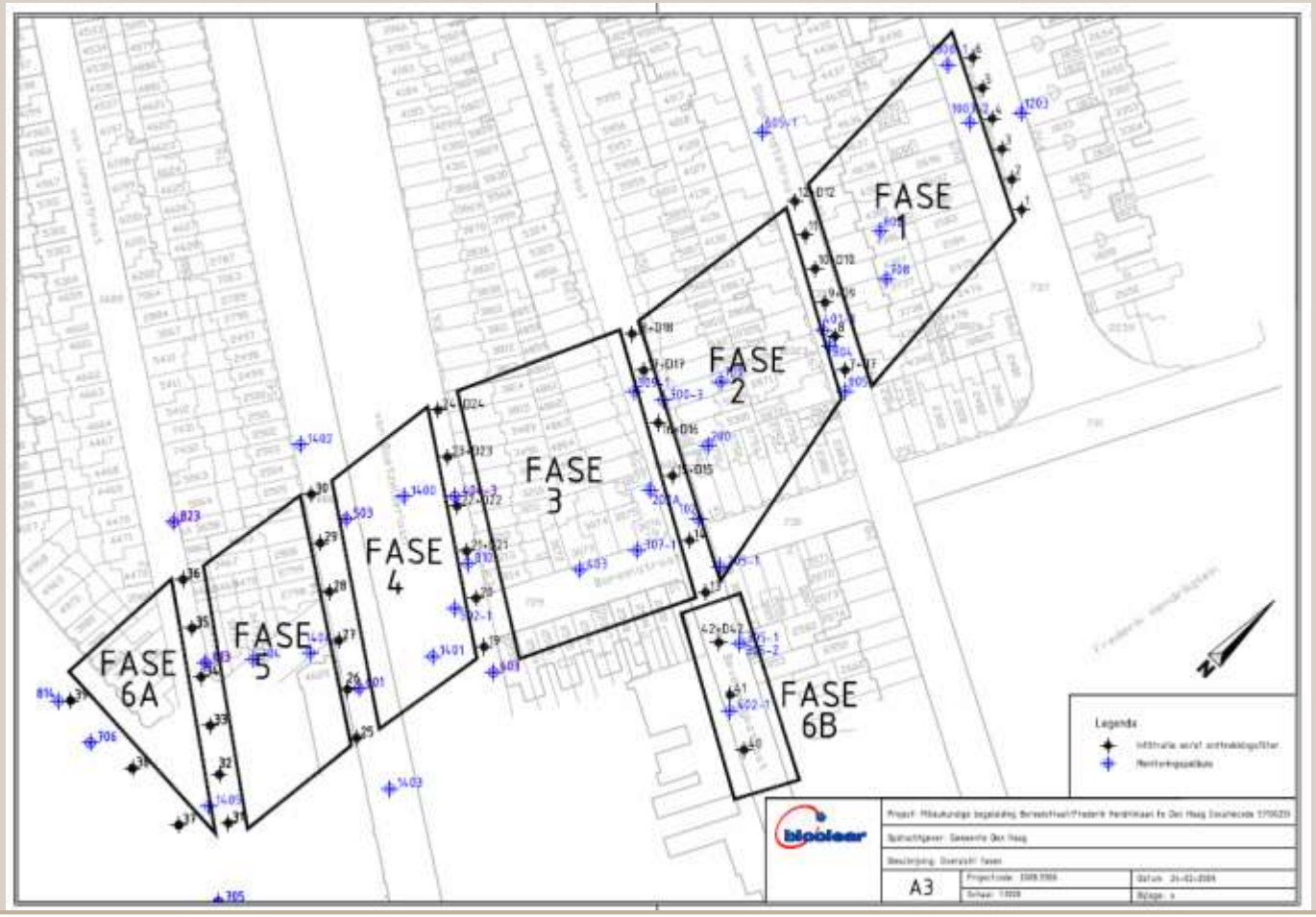
Design



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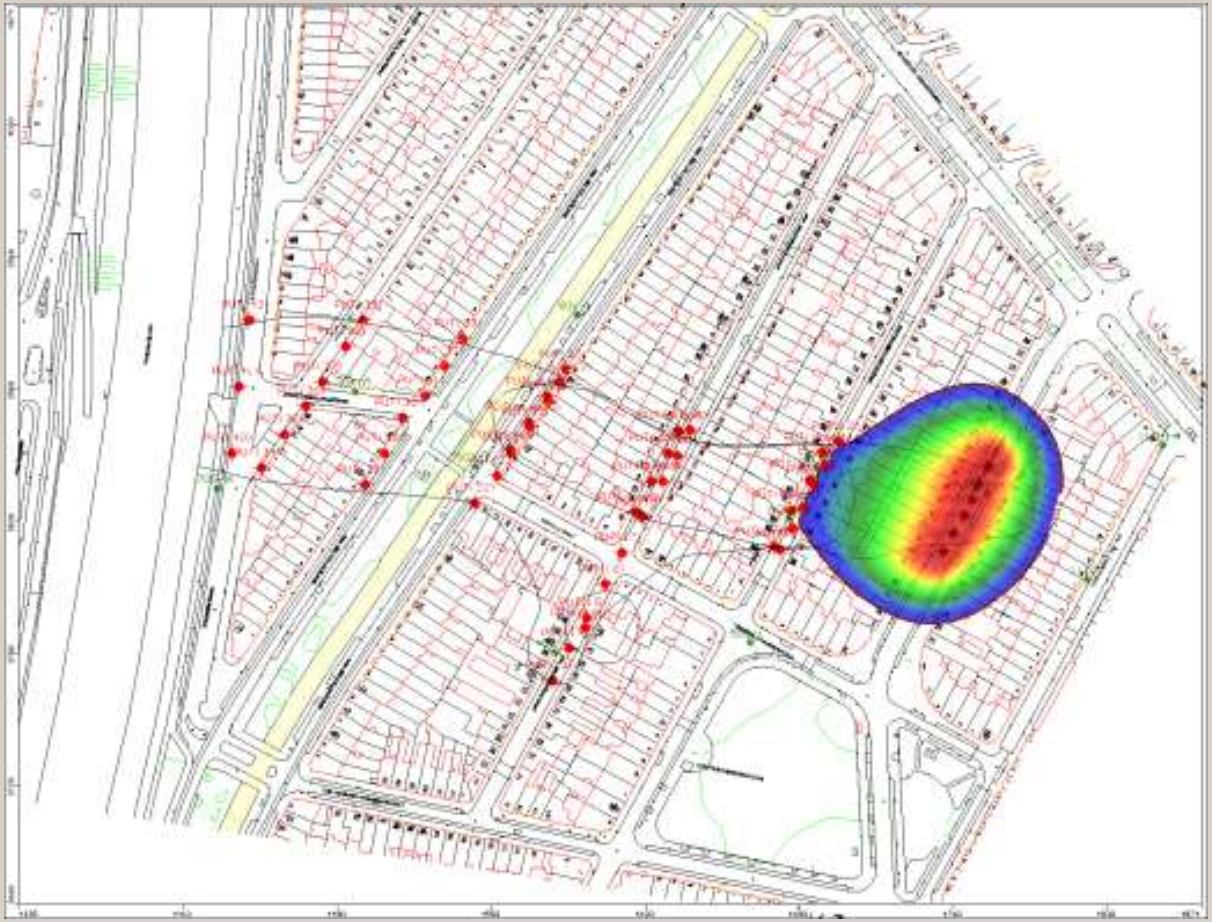
Phase 1
(t=90 d)



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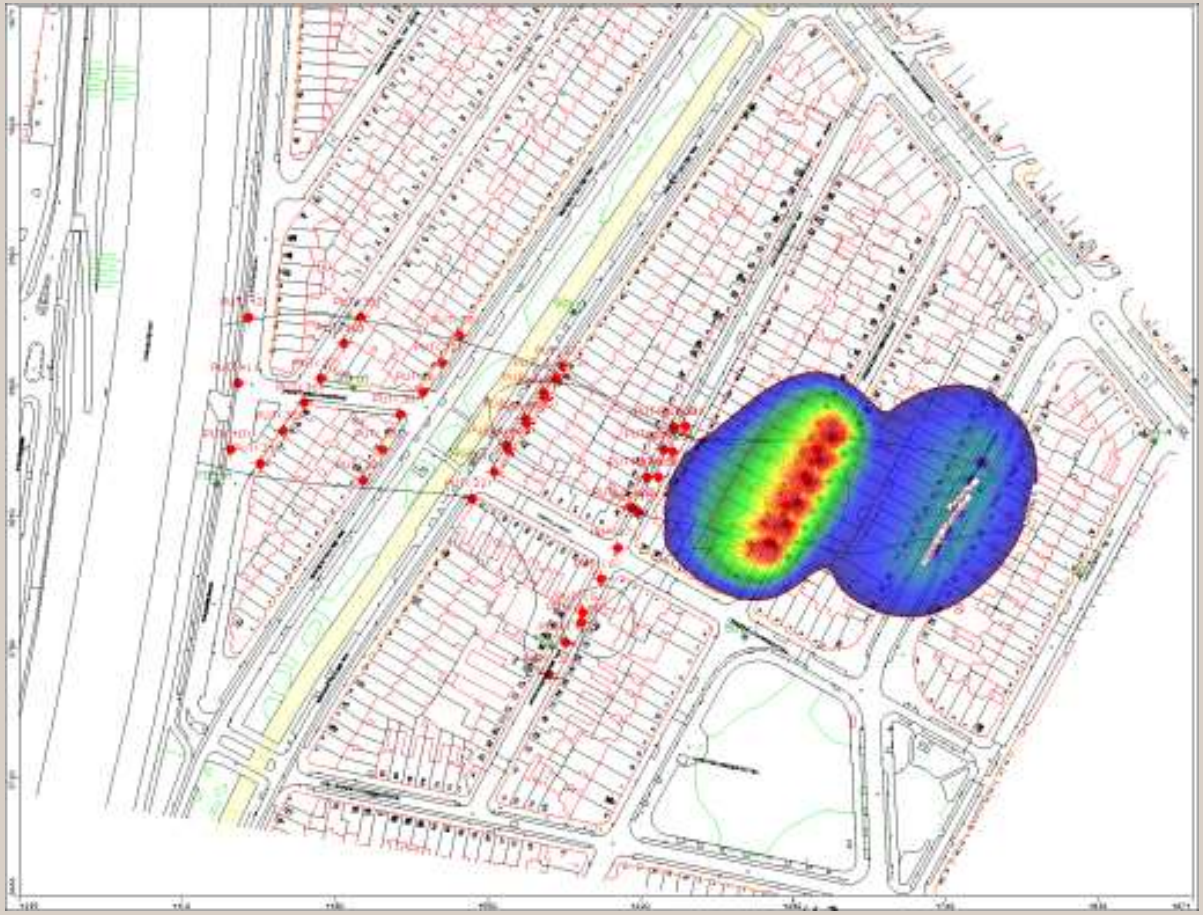
Phase 2
(t=180 d)



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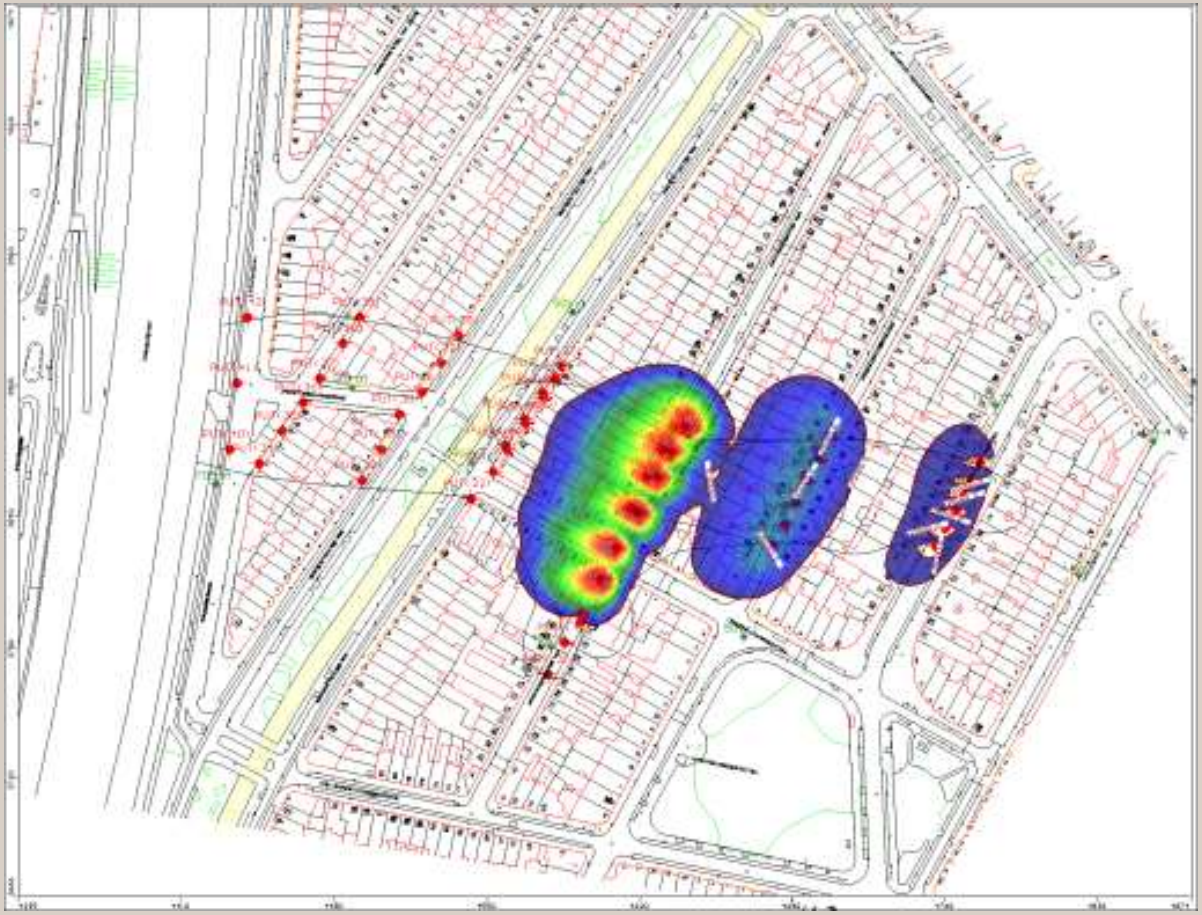
Phase 3
(t=270 d)



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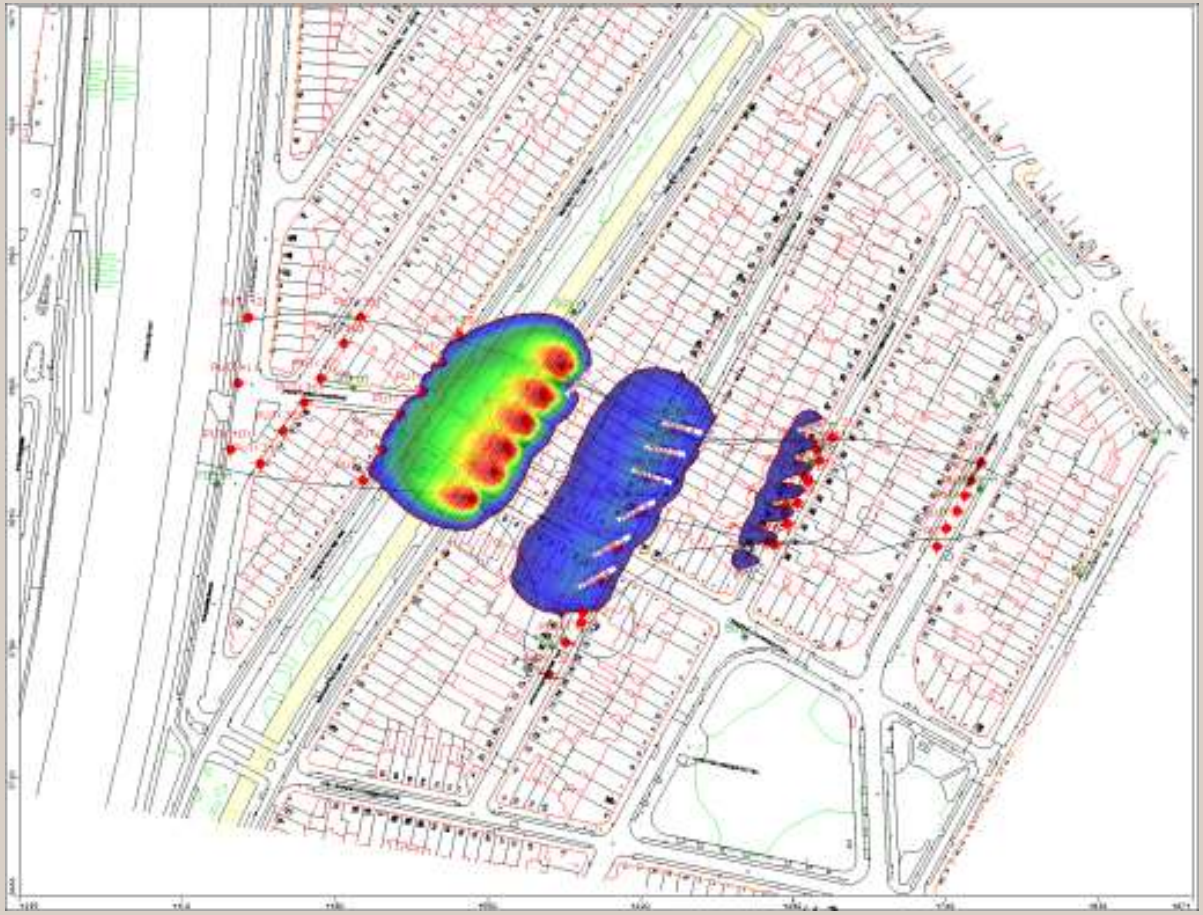
Phase 4
(t=360 d)



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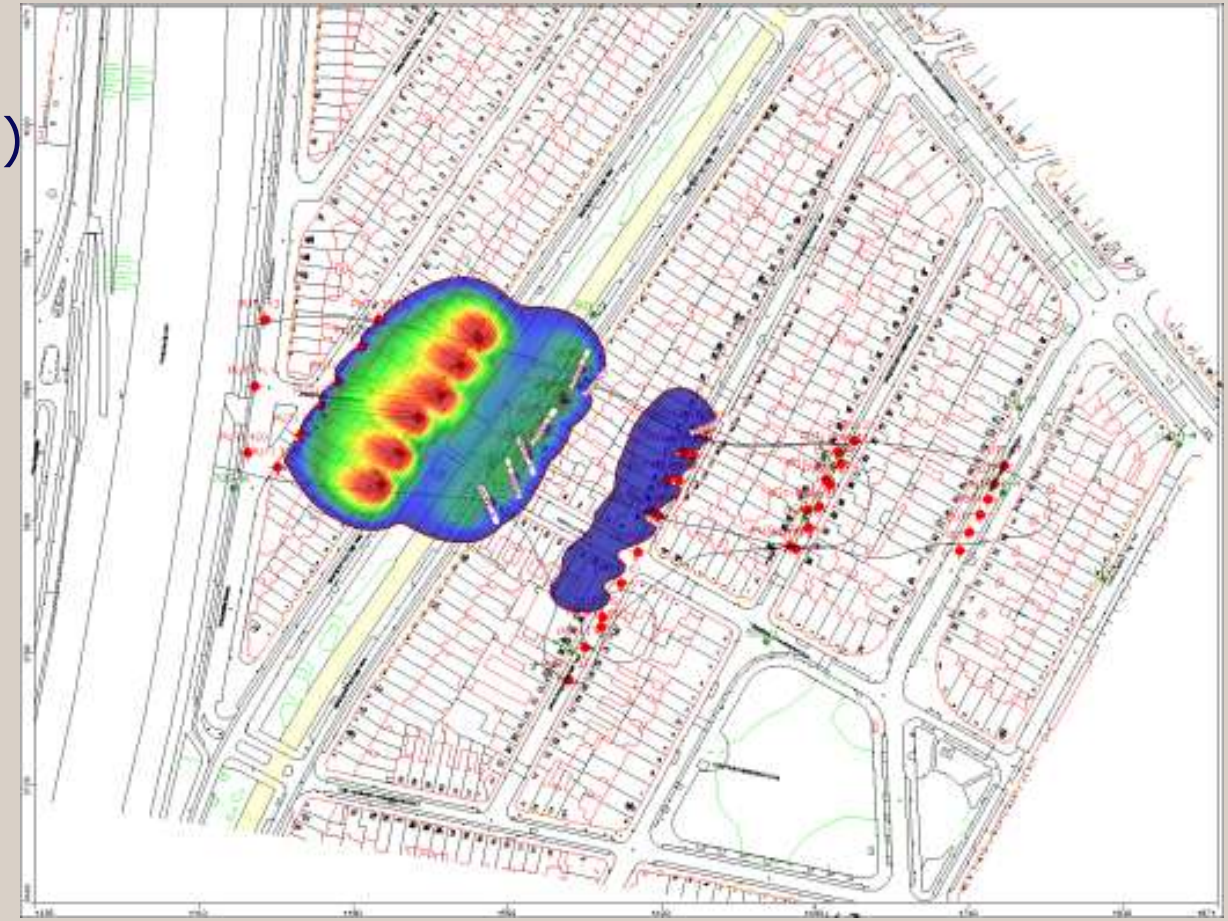
Phase 5
(t=420 d)



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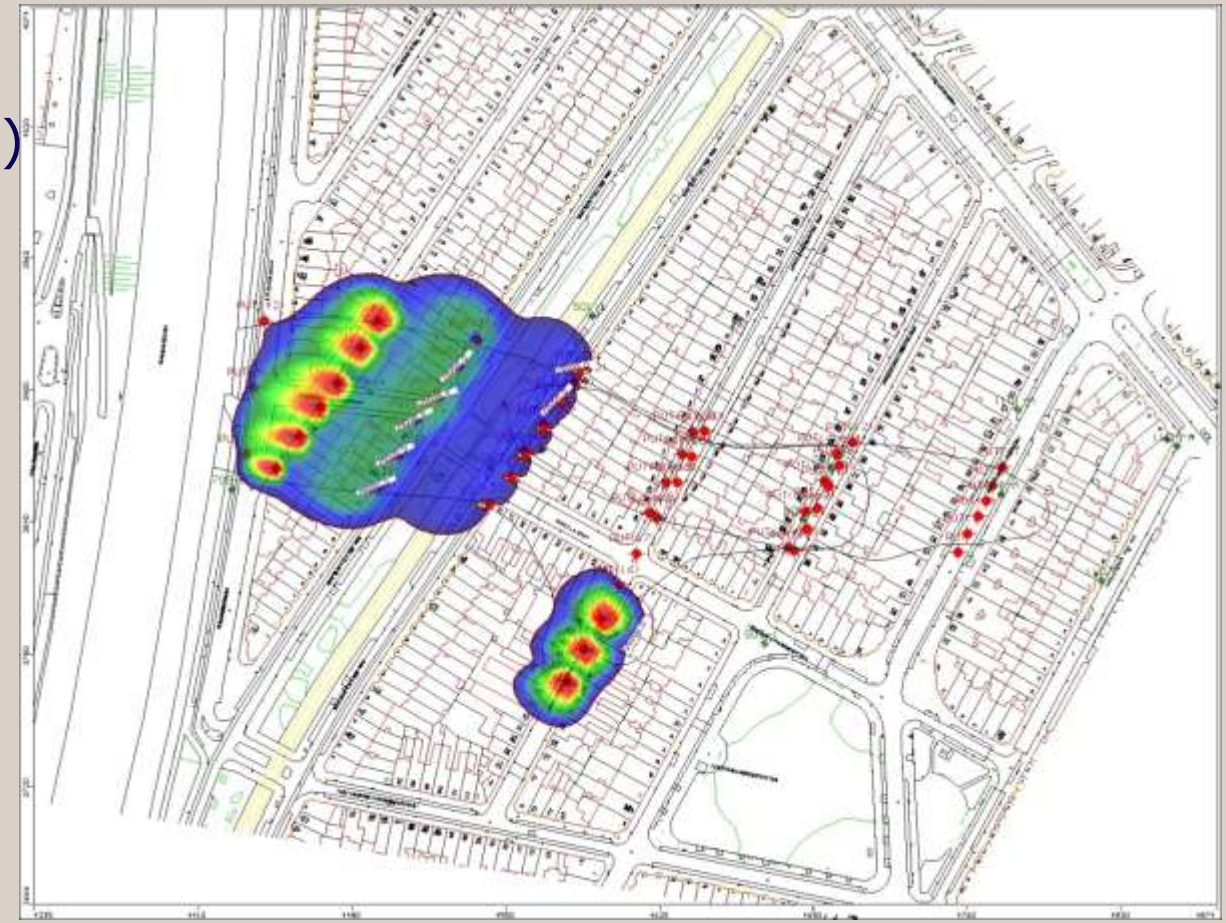
Phase 6
(t=480 d)



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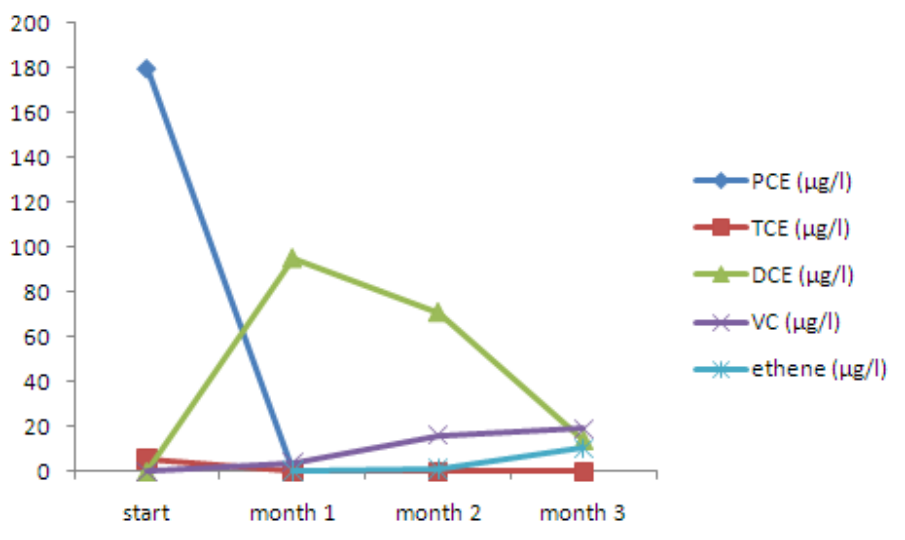
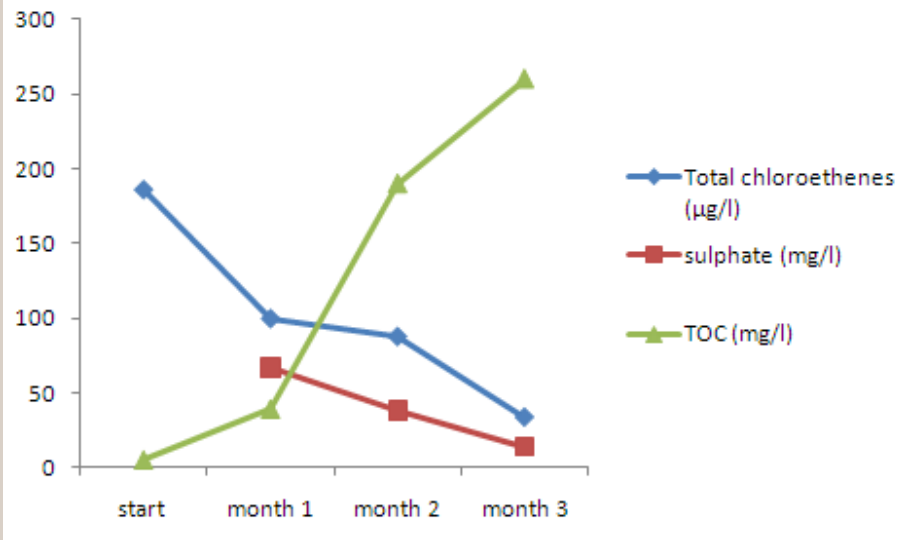
Boreelstraat The Hague

- Decreasing cloroethene concentrations
- Improved soil conditions for biological remediation





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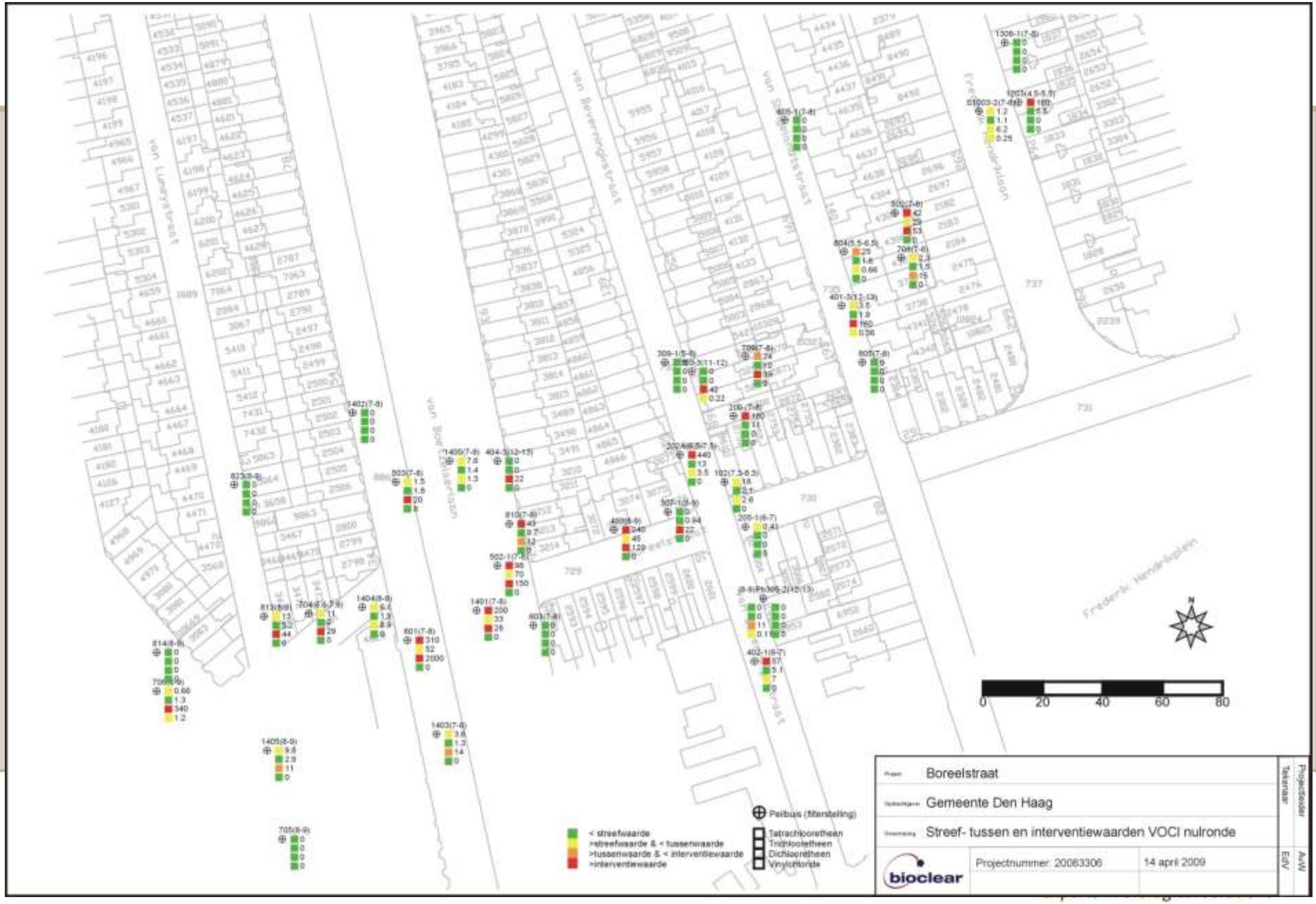
Boreelstraat
Gemeente Den Haag
Streef- tussen en interventiewaarden VOCI nulronde
bioclear
Projectnummer: 20083306
14 april 2009
Peilbuis (filterstelling)
< streefwaarde
>streefwaarde & < tussenwaarde
>tussenwaarde & < interventiewaarde
>interventiewaarde
Tetrachloorethen
Trichloorethen
Dichloorethen
Vinylchloride
0
20
40
60
80
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Boreelstraat
Gemeente Den Haag
VOCl concentraties verificatieronde 1
Projectnummer: 20083306
17 november 2010
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Peilbuis (filterstelling)
< streefwaarde
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>interventiewaarde
Tetrachloorethenen
Trichloorethenen
Dichloorethenen
Vinylchloride
0
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Summary TCE remediations

Site	soil	K (m/d)	volume (m^3)	start [VOC] (ug/l)	end [VOC] (ug/l)	active phase (months)
Hoogeveen	sand	15	400,000	50,000	< 10	9
Almelo	fine sand	10	12,000	15,000	< 1	4
Twello	sand	10-20	50,000	7,500	< 10	10
The Hague	sand	10	3,000	3,000	in progress	5 (est.)
The Hague	sand	15	400,000	1,000	<1	3 months per Phase
Driebergen	sand	8	2,500	2,500	in progress	4-6 (est.)
Copenhagen	Sand-stone	20-30	2,350	20	< 0.5	3

cost indication for plumes of > 10,000 m^3: 3-8 €/m^3 soil volume

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Energy, including production of Carbon source

Parameter	P&T	TCE-concept	Ozone
Energy	700.000 KWH	63.000 KWH	600.000 KWH
C-source production		304.000 KWH	
Per m3	8,8 KWH/M3	3,8 KWH/M3	7,9 KWH/M3
CO2-total	397.000 KG	244.000 KG	361.000 KG
	5,0 KG/M3	3,1 KG/M3	4,5 KG/M3

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Conclusions

Using bioaugmentation, very low concentrations (< 1 µg/l) can be reached within 1 to 2 years

Not only useful when *Dehalococcoides ethenogenes* is absent, but also when redox conditions are moderately reduced and numbers of *Dehalococcoides ethenogenes* are low

The TCE concept is especially interesting for large plume remediations

Savings compared to conventional pump&treat in the order of 30-50%, short active phase, then monitoring phase

TCE is also a sustainable solution in comparison with conventional techniques

Bio-augmentation =
a powerful proven technology

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Thanks for your attention!

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