Sediment Biobarriers for Chlorinated Aliphatic Hydrocarbons in Groundwater Reaching Surface Water

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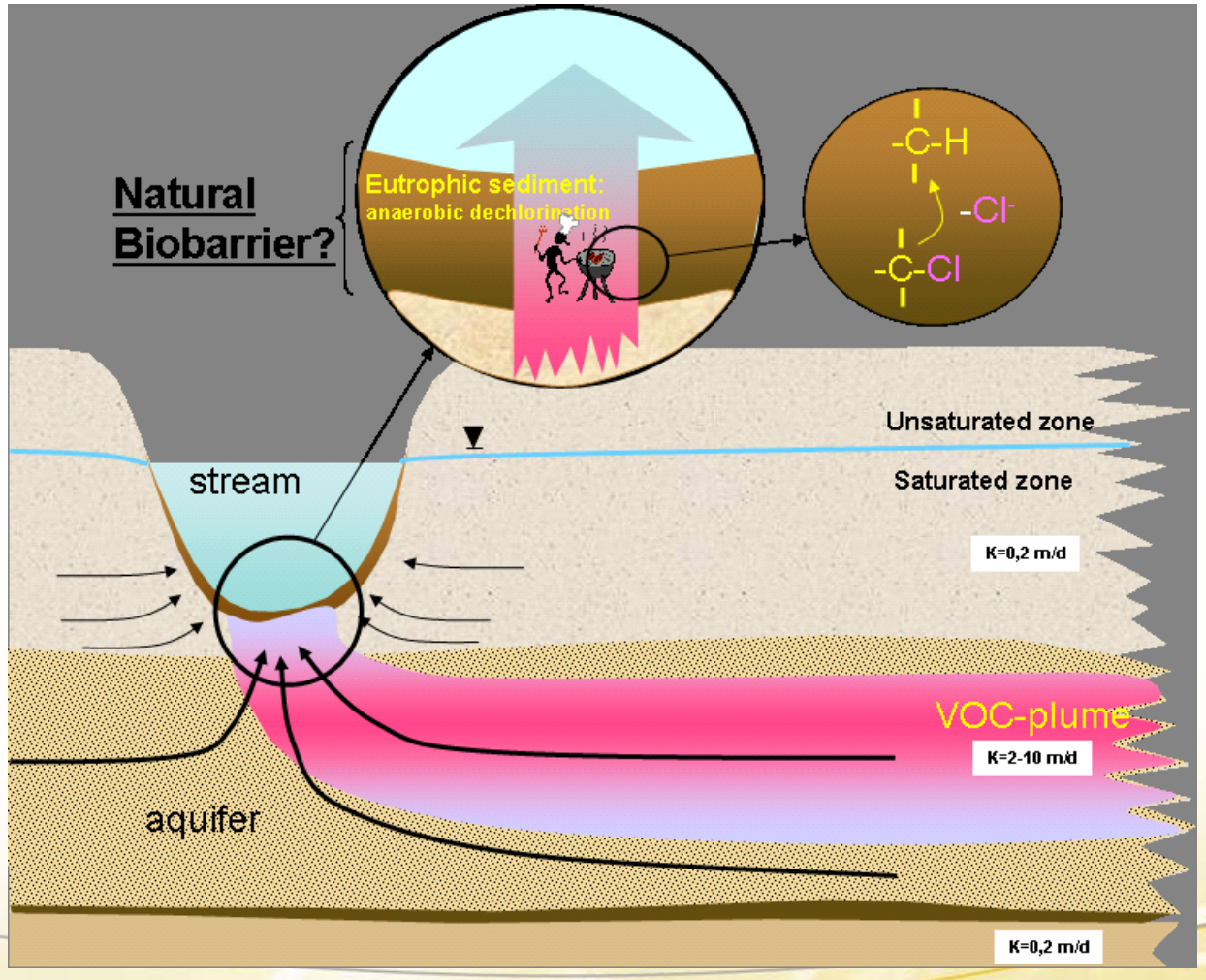
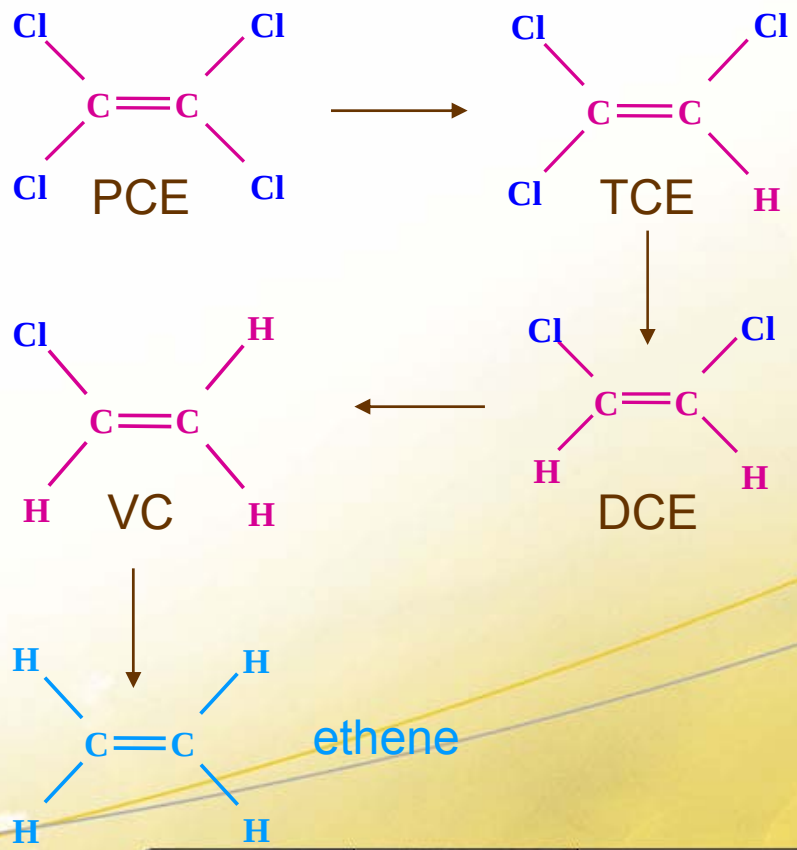
NATO/CCMS Pilot study
Prevention and Remediation in Selected Industrial Sectors: Sediments
Ljubljana, Slovenia, June 17 – 22, 2007

Problem: groundwater moving to surface water

Sediment: natural biobarrier?

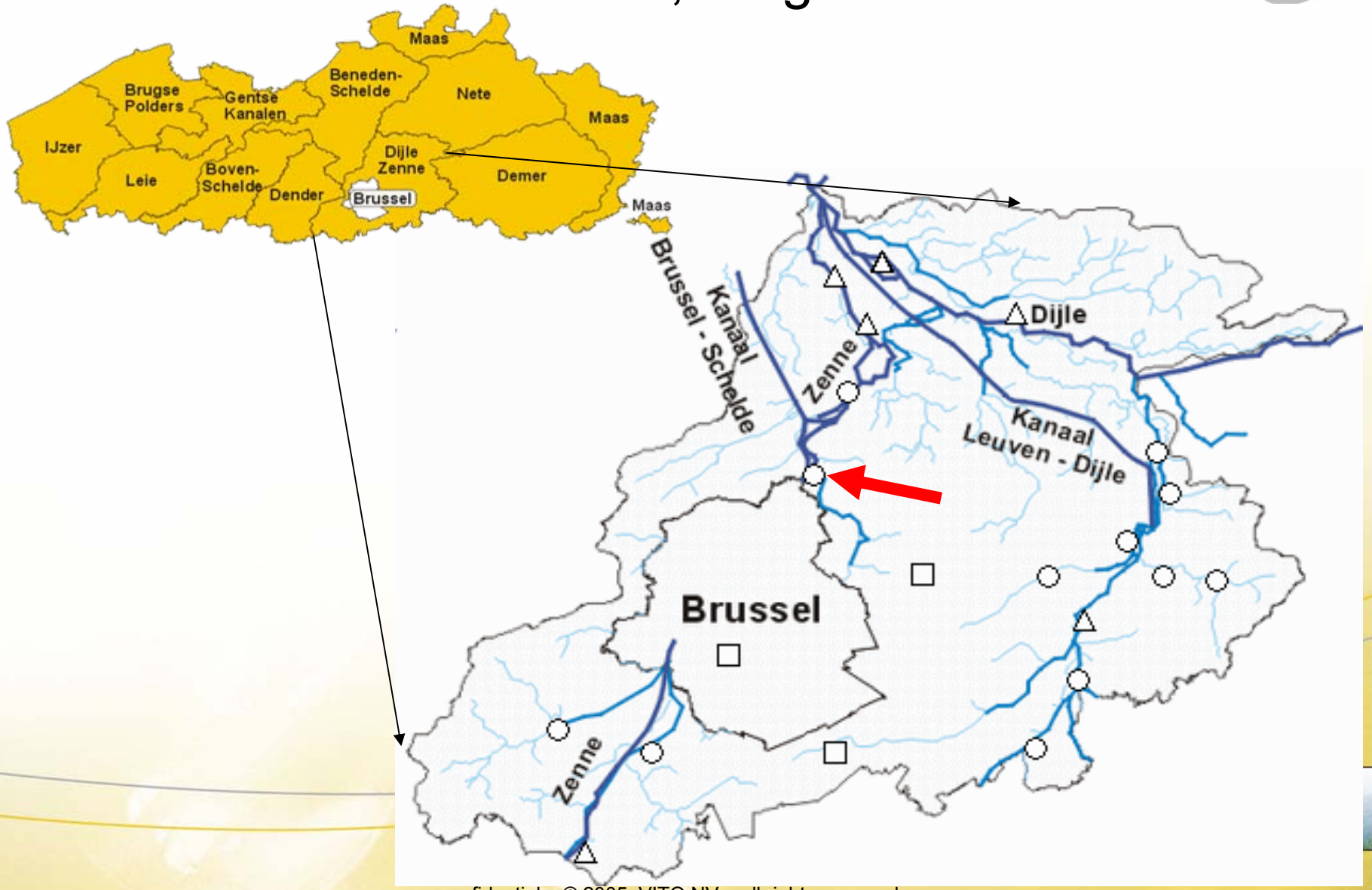


Model Compound: CAHs



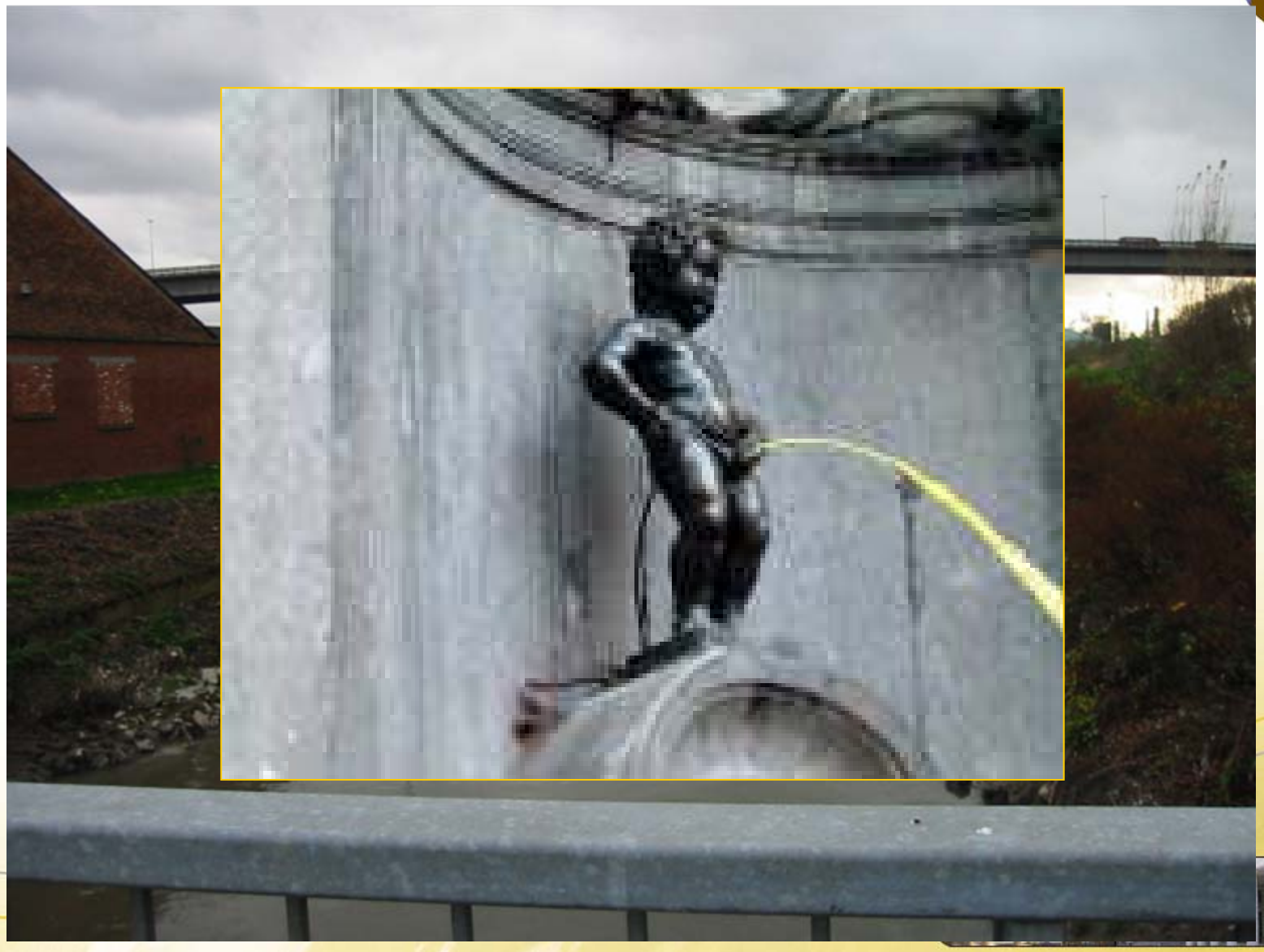
Study Site: Zenne river

Vilvoorde, Belgium

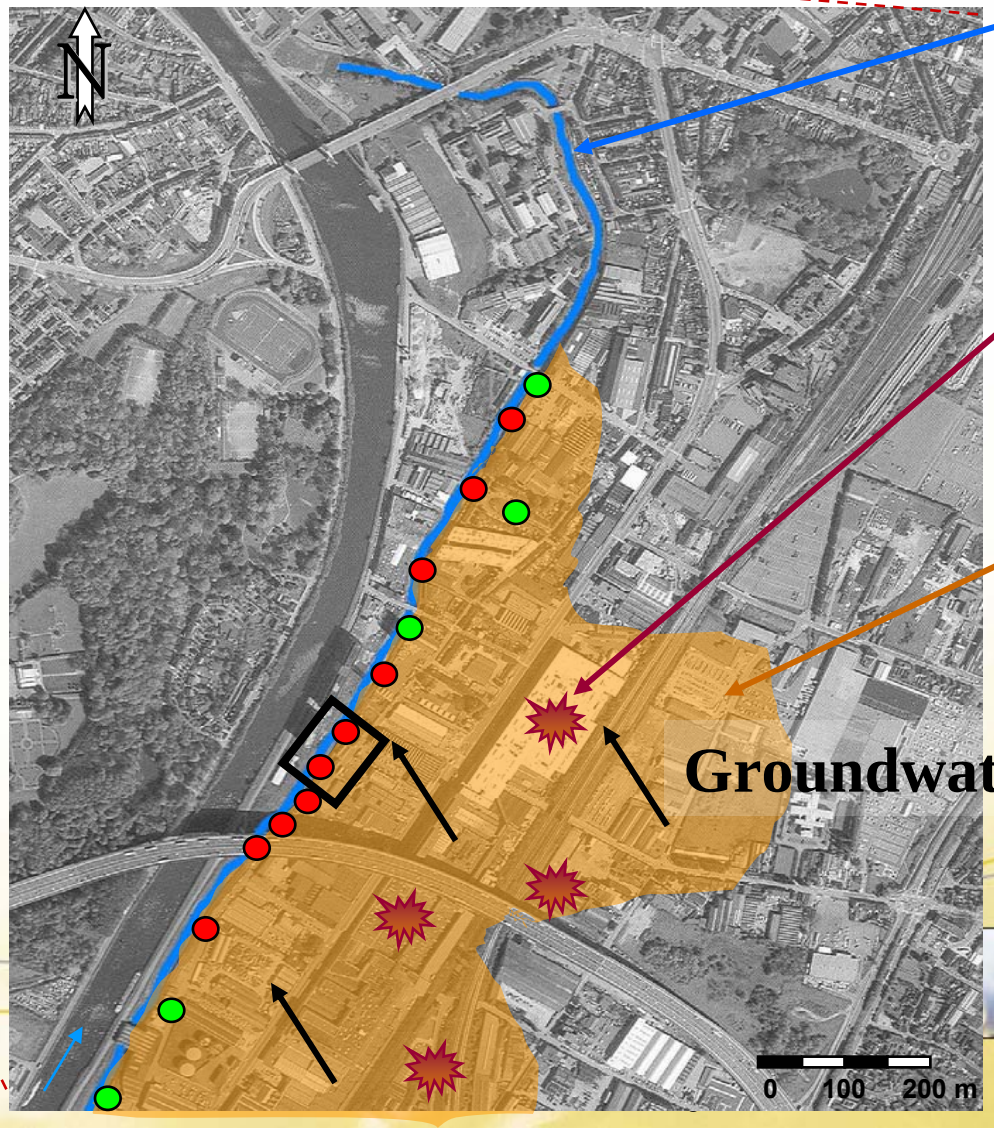


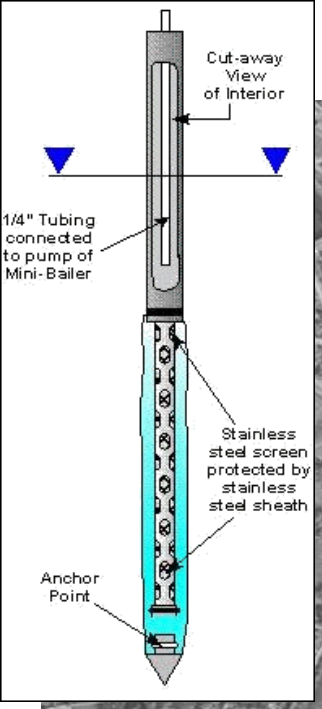
The Zenne is very eutrophic

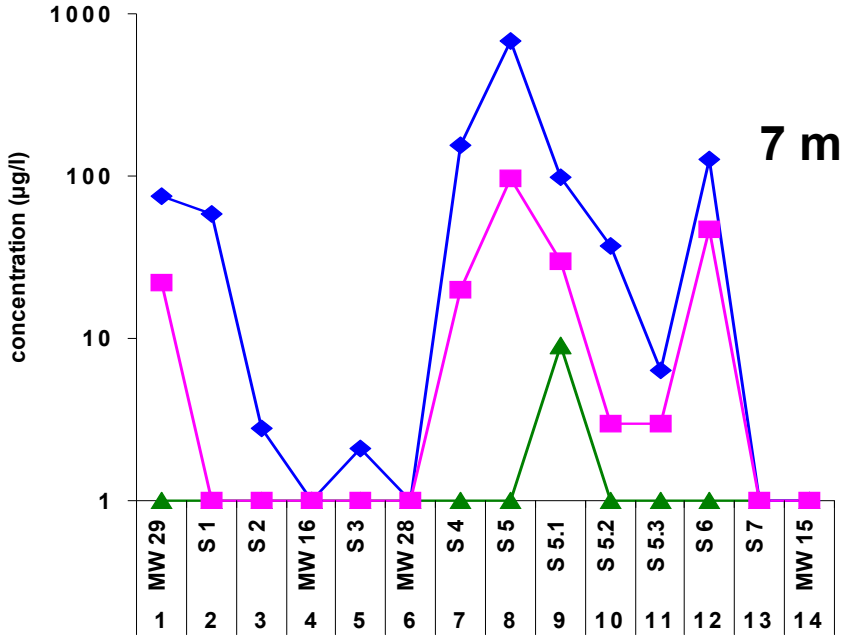
Since untreated sewage water from Brussels flows into it

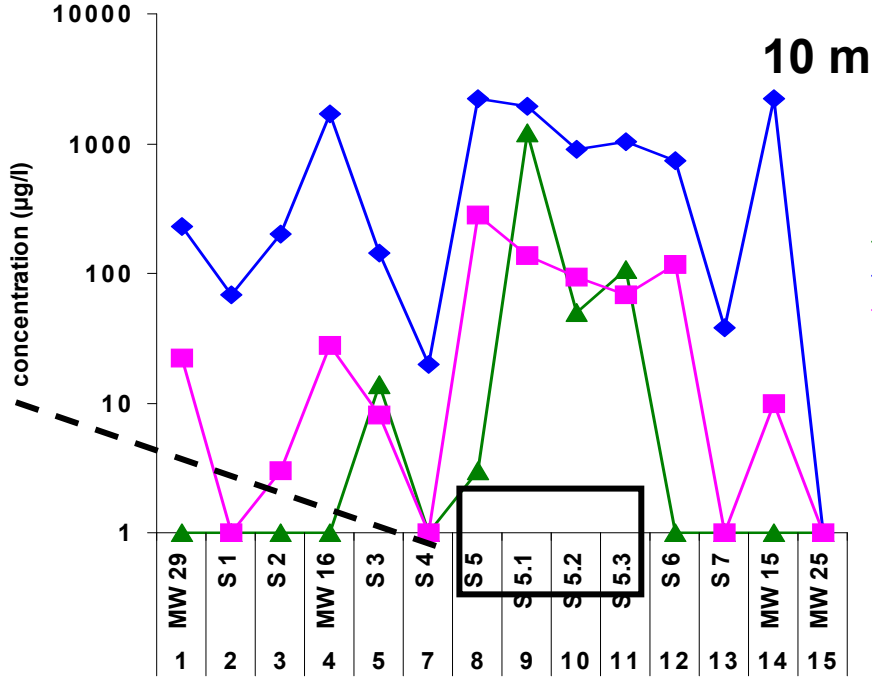


Study Site: Zenne river,
Vilvoorde, Belgium



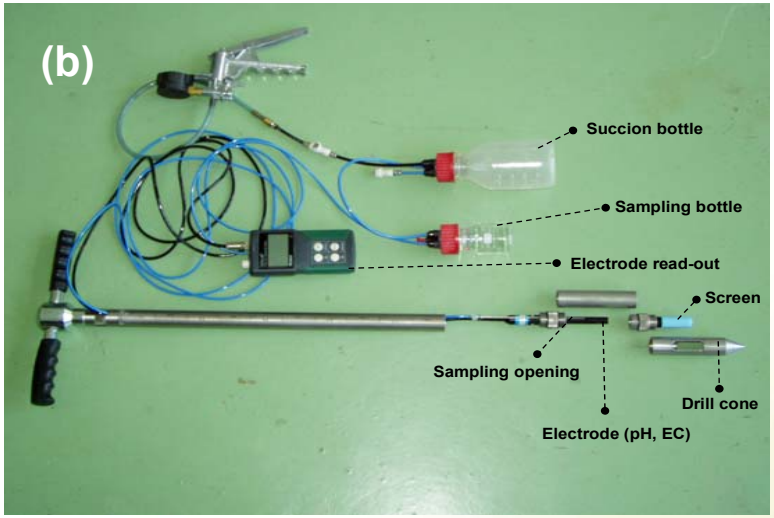


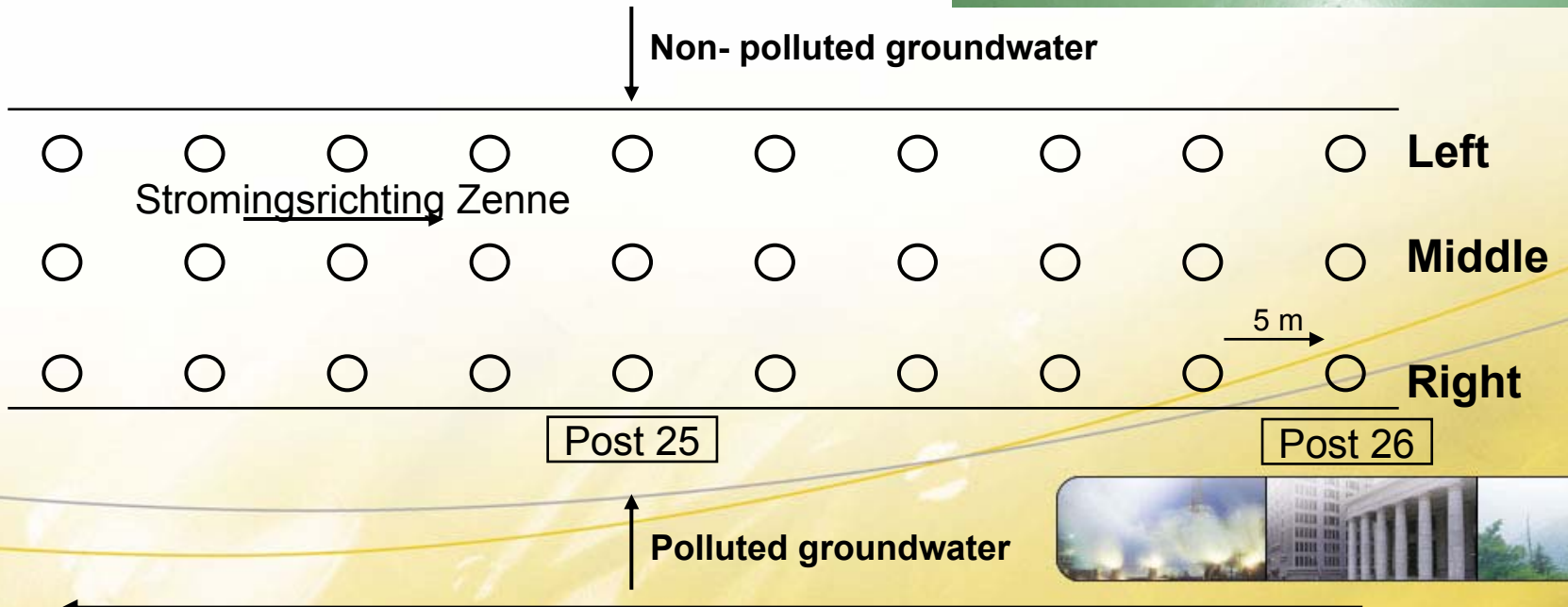




- Monitoring well
- Screenpoint

Analysis of CAH in sediment and pore water

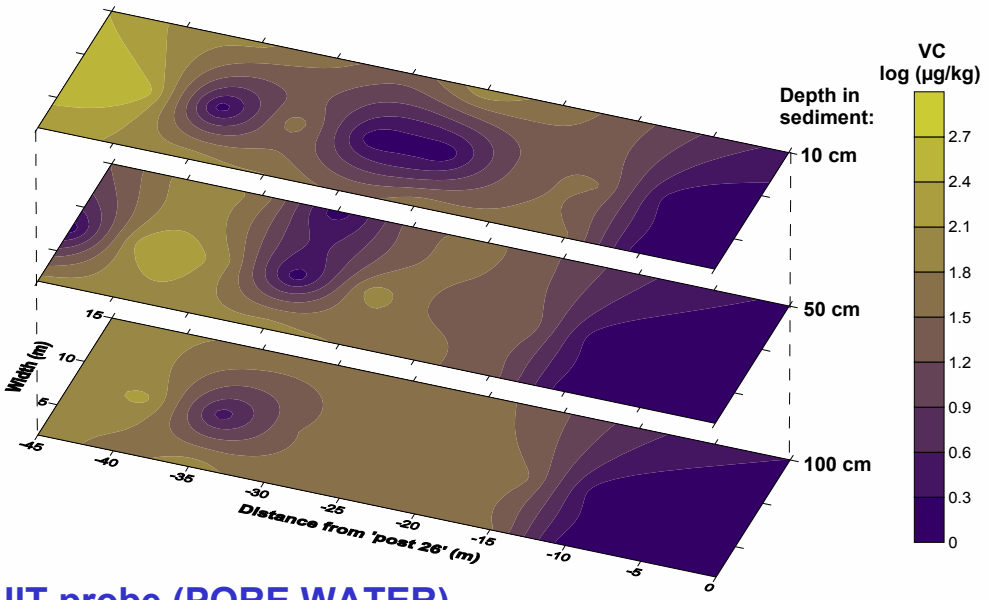




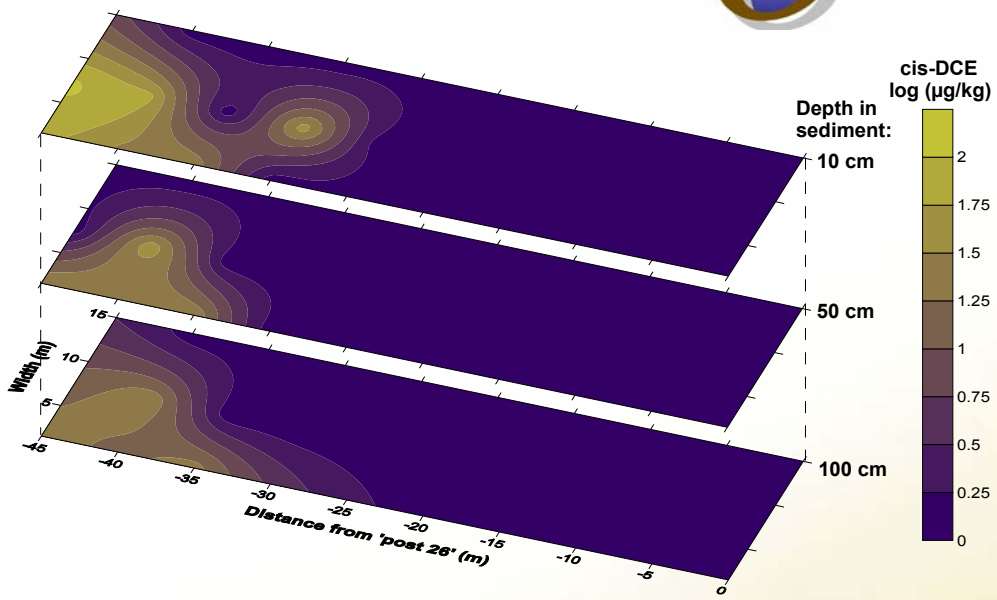
CAH influx zones in the river bed

Piston sampling (SEDIMENT)

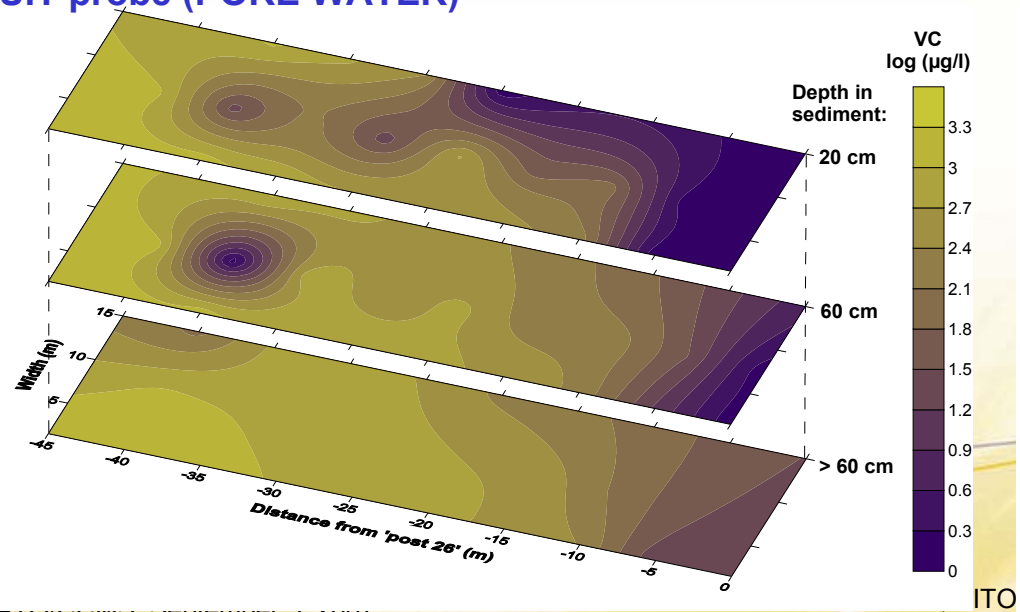
VC

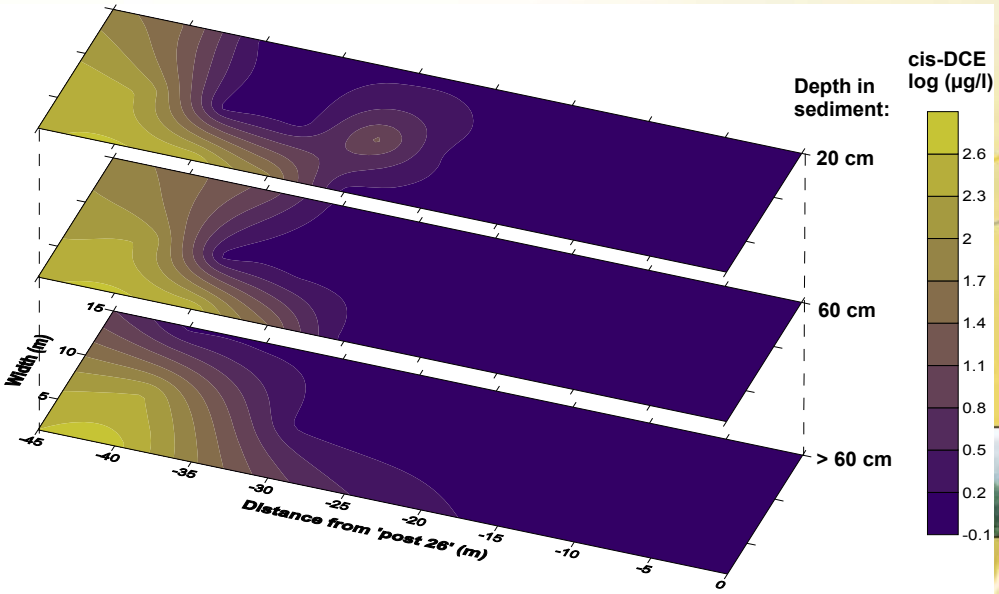


cis-DCE



UIT probe (PORE WATER)

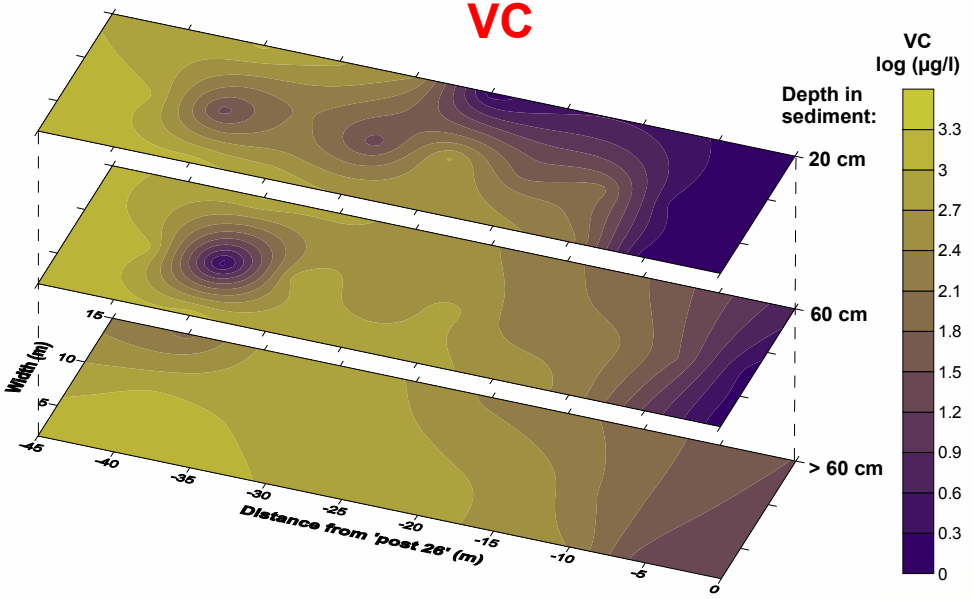




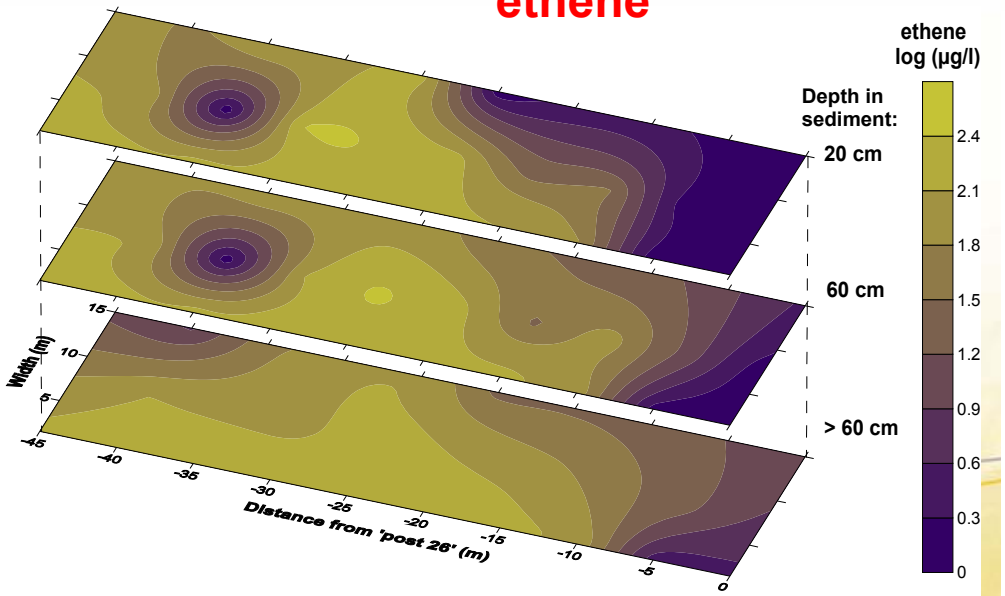
CAH influx zones in the river bed

UIT probe (PORE WATER)

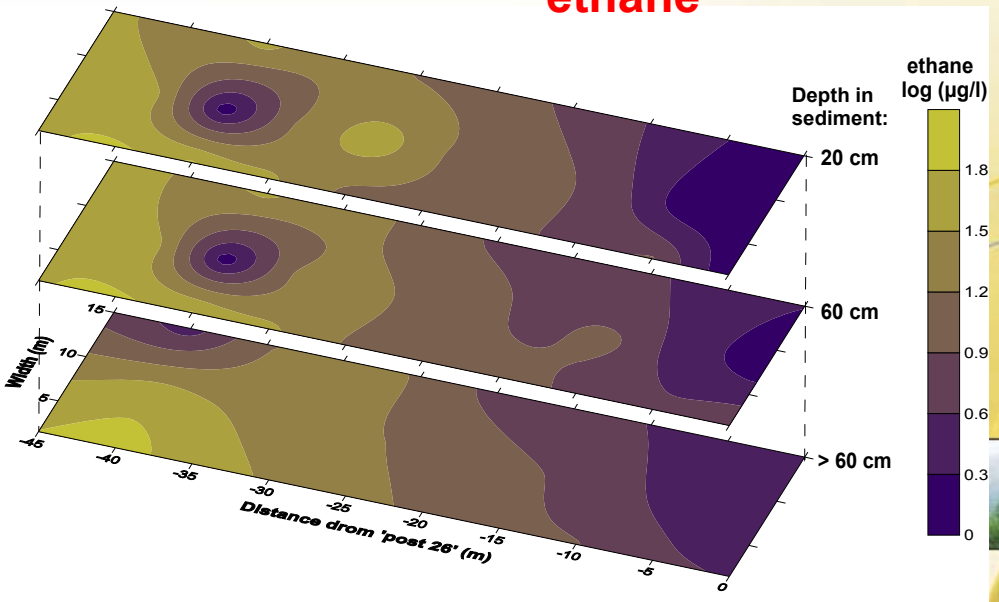
VC



ethene



ethane



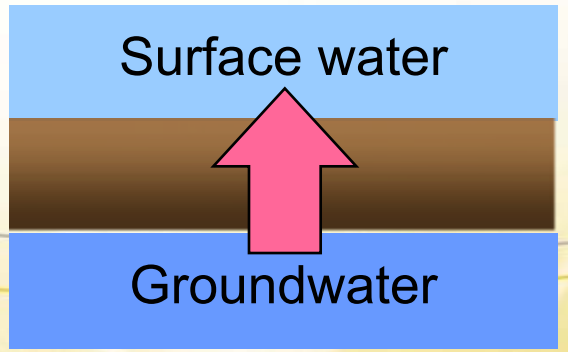
Determination of surface water influx zones in the river bed by stable isotope analysis

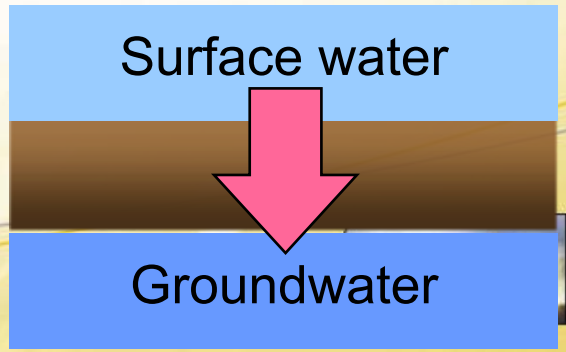
Hydrogen H and oxygen O specific isotope analyses

$$R = \frac{^{2}H}{^{1}H} \rightarrow \delta^{2}H = \left(\frac{R_{sample} - R_{reference}}{R_{reference}} \right) * 1000 \text{ (‰ V-SMOW)}$$

$$R = \frac{^{18}O}{^{16}O} \rightarrow \delta^{18}O = \left(\frac{R_{sample} - R_{reference}}{R_{reference}} \right) * 1000 \text{ (‰ V-SMOW)}$$

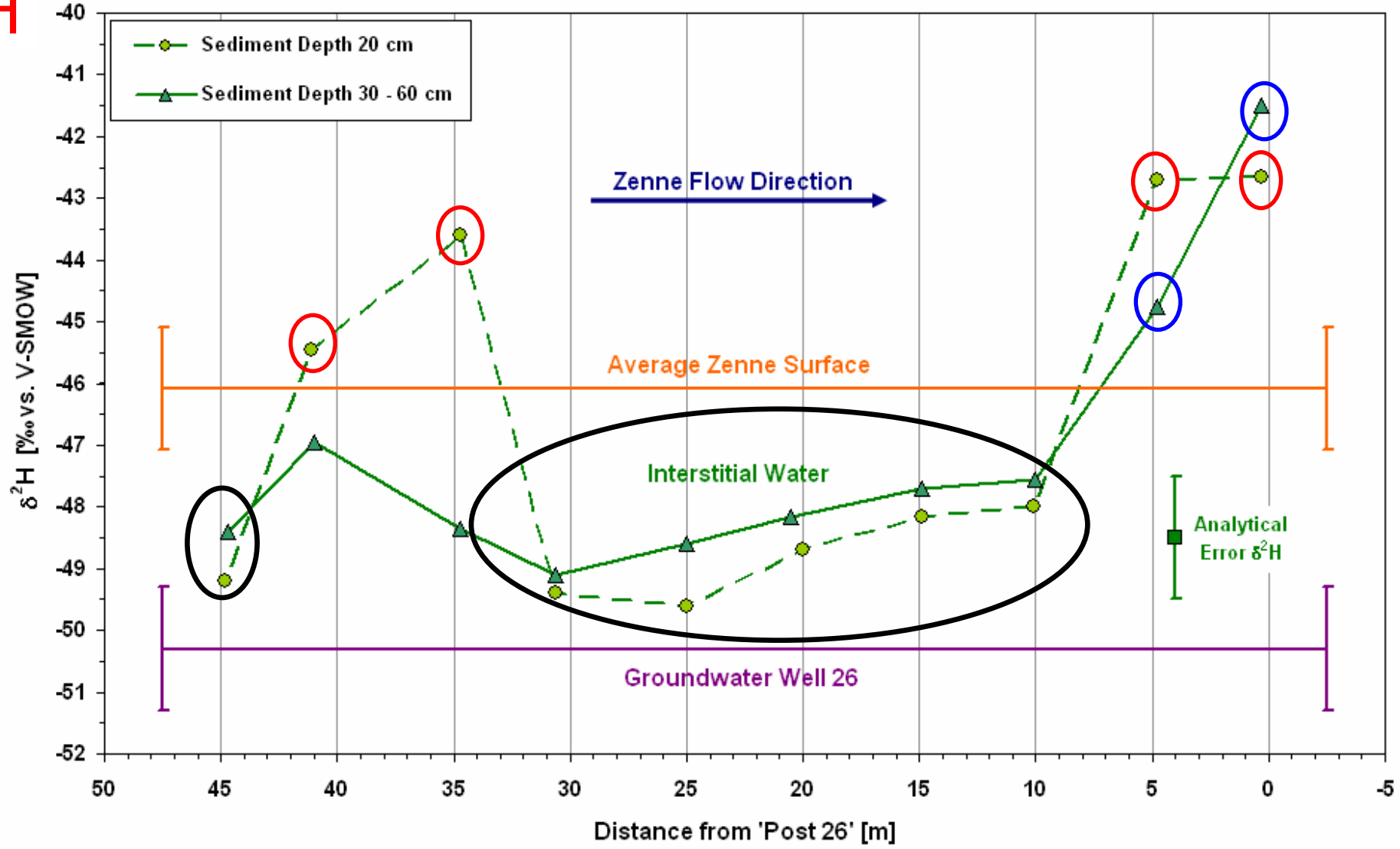
$\delta^{2}H$ en $\delta^{18}O$ groundwater ≠ surface water





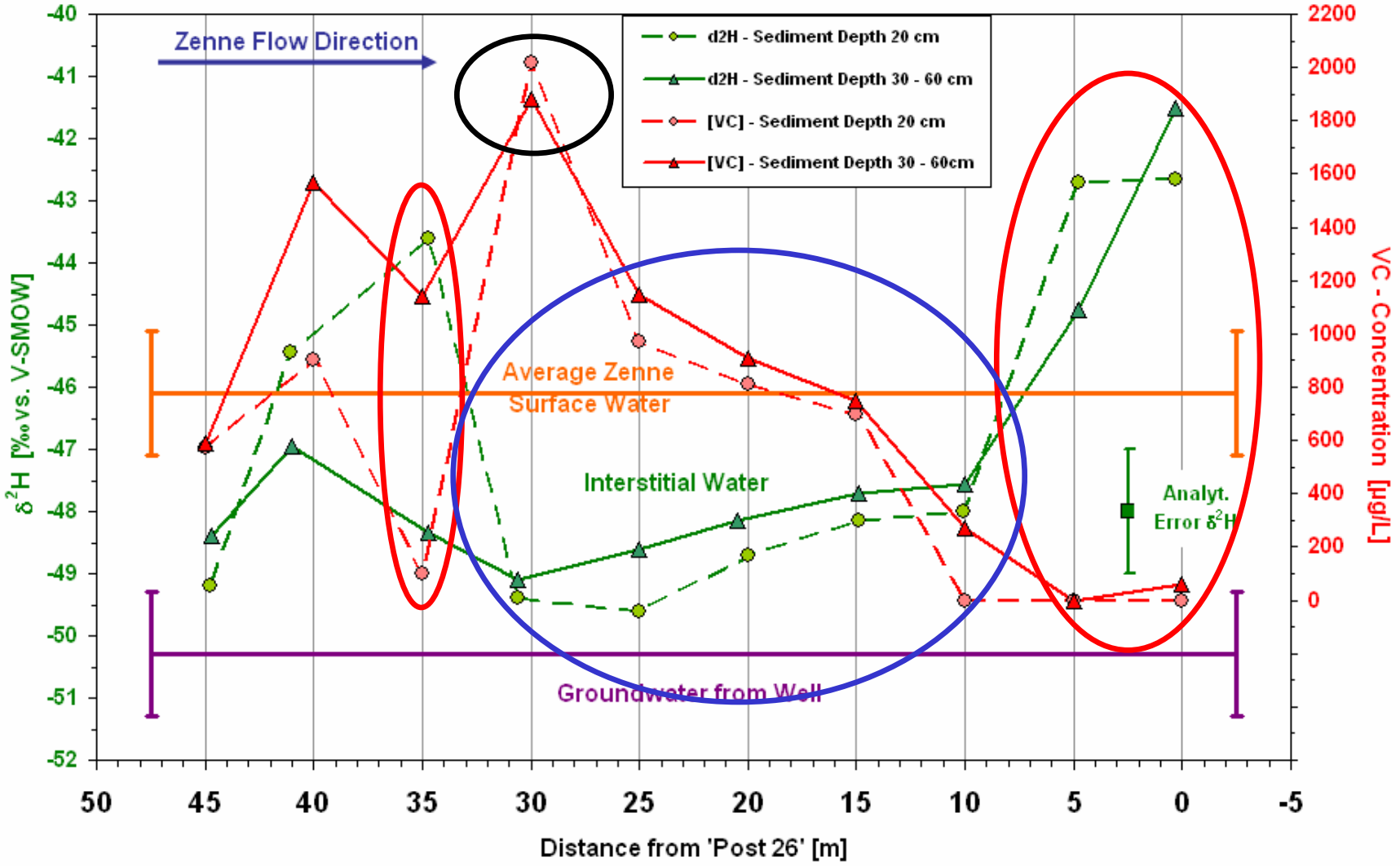
Determination of surface water influx zones in the river bed

δ^2H

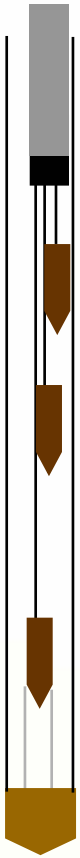


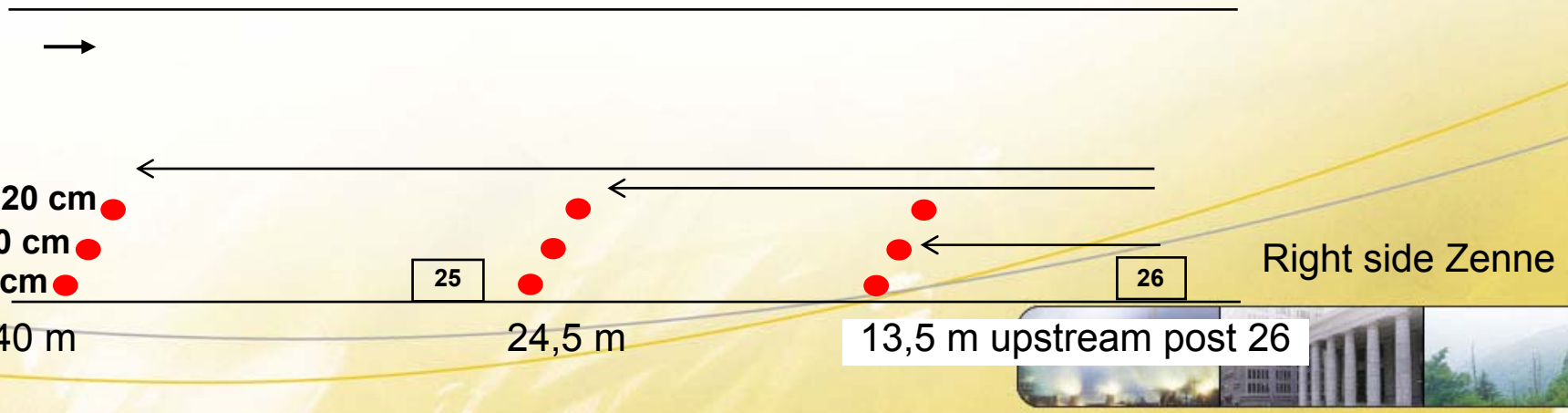
Determination of surface water influx zones in the river bed

$\delta^2H \leftrightarrow [VC]$



On line *in situ* monitoring of physico-chemical parameters
Teflon pore water samplers

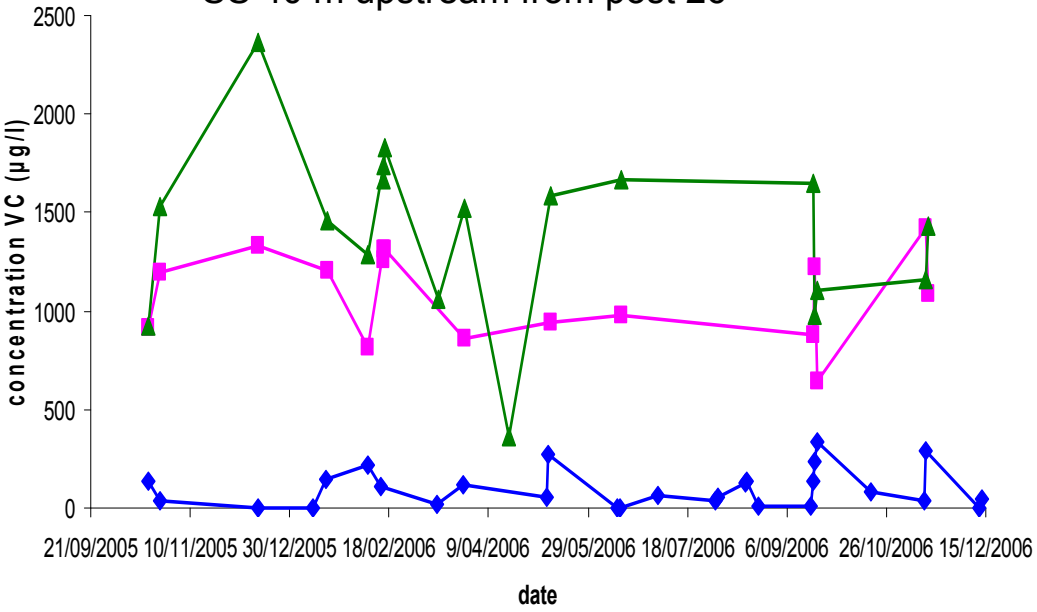


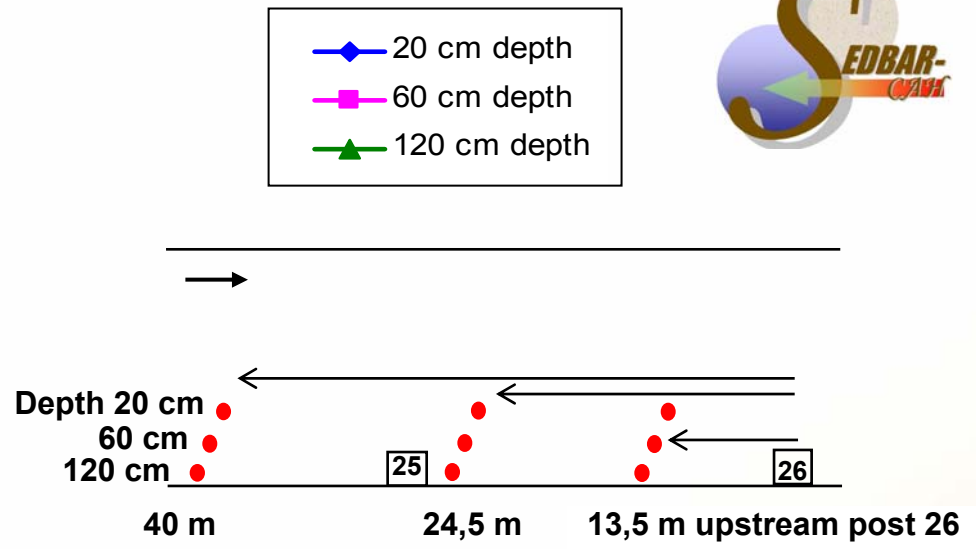


VC

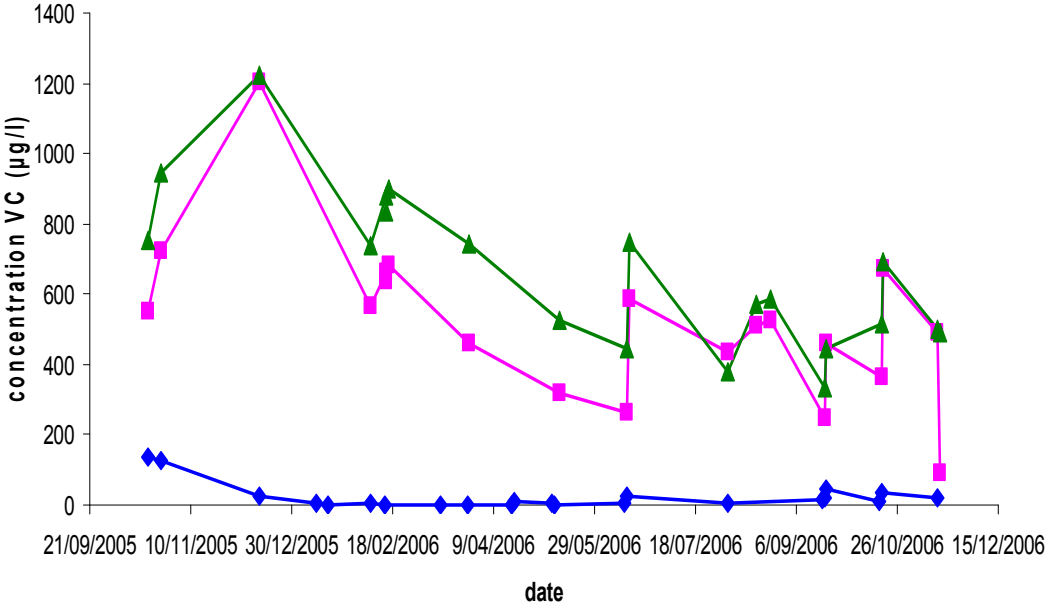
Belgian sanitation norm VC: 5 µg/l

SS 40 m upstream from post 26

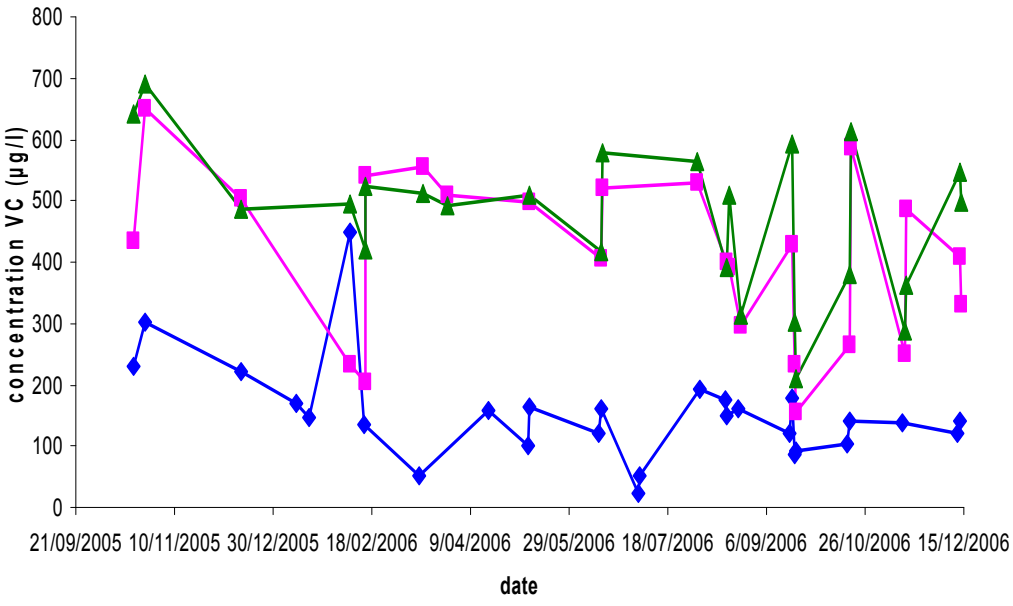




SS 24,5 m upstream from post 26



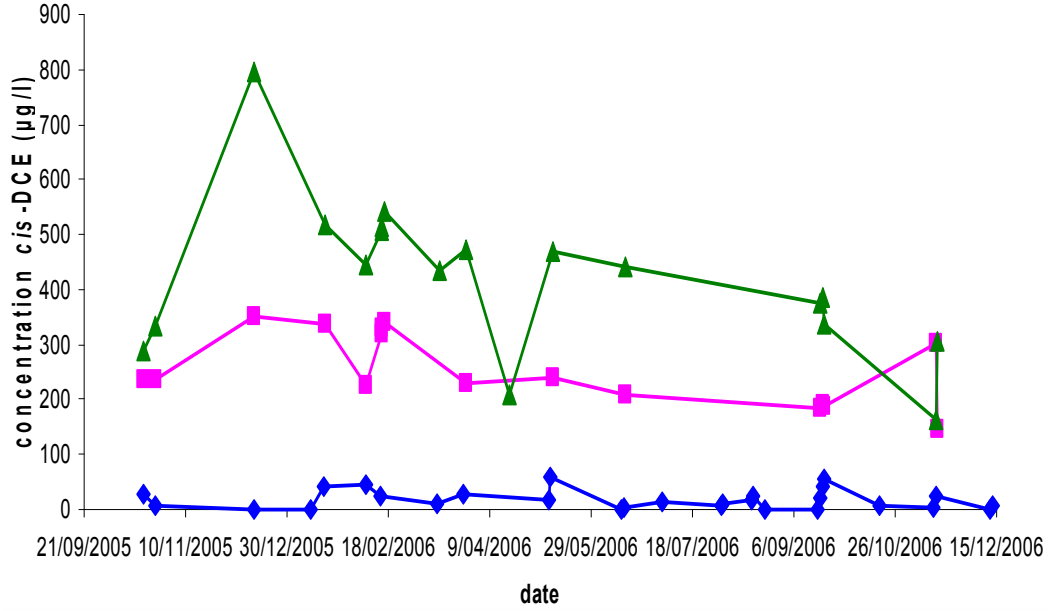
SS 13,5 m upstream from post 26

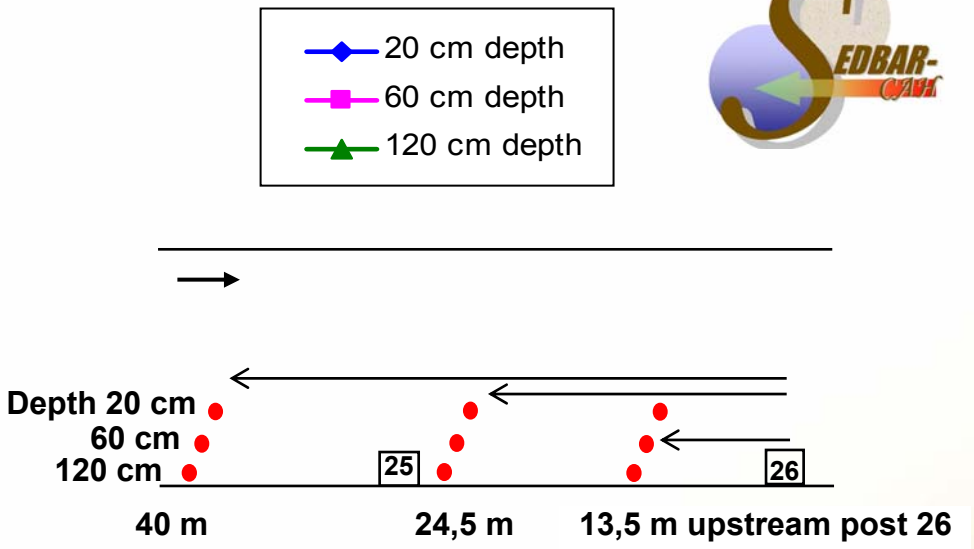


Cis-DCE

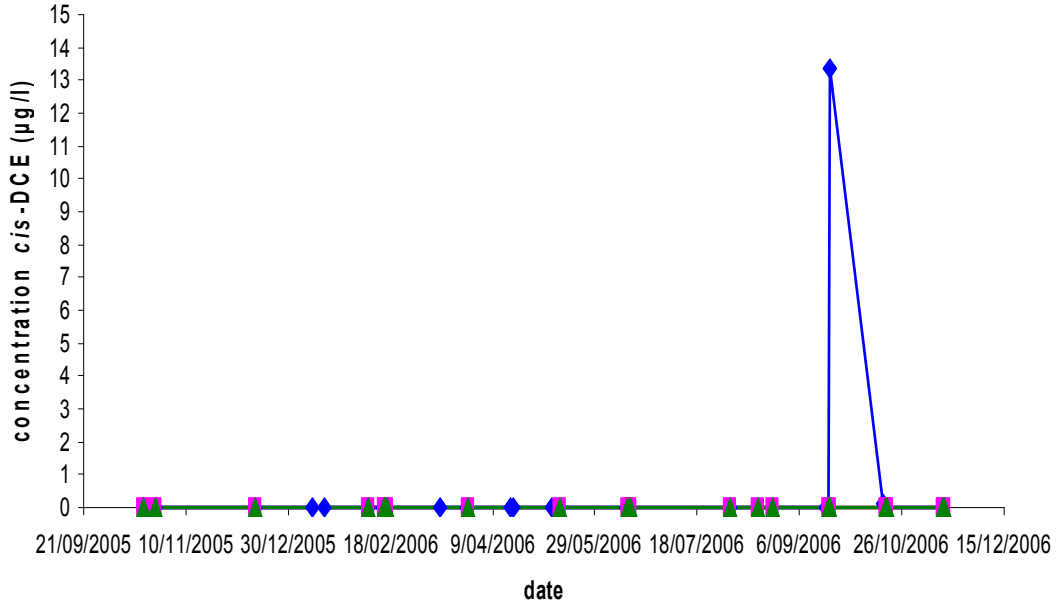
Belgian sanitation norm *cis*-DCE + *trans*-DCE: 50 µg/l

SS 40 m upstream from post 26

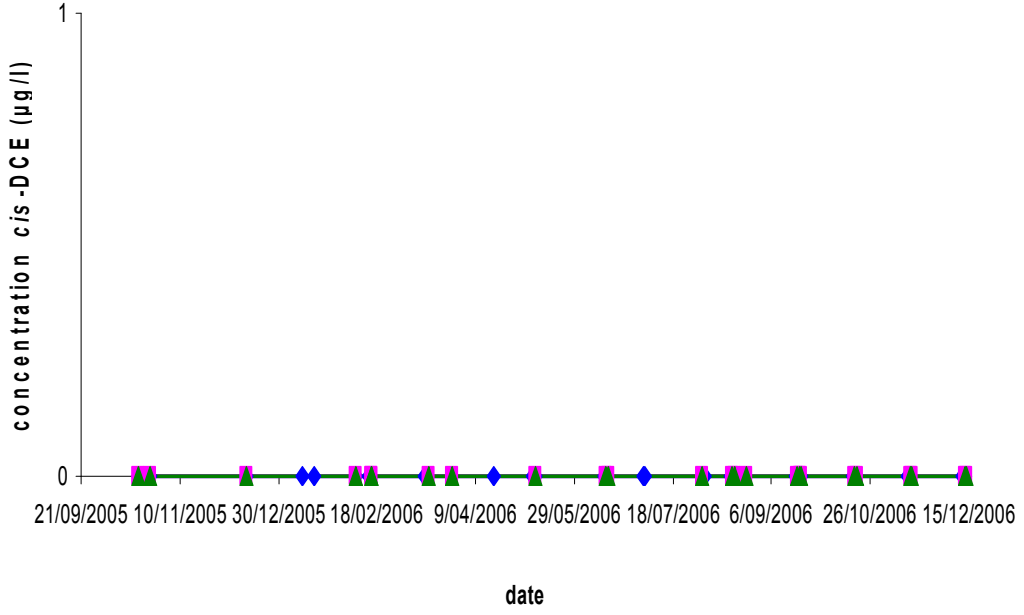




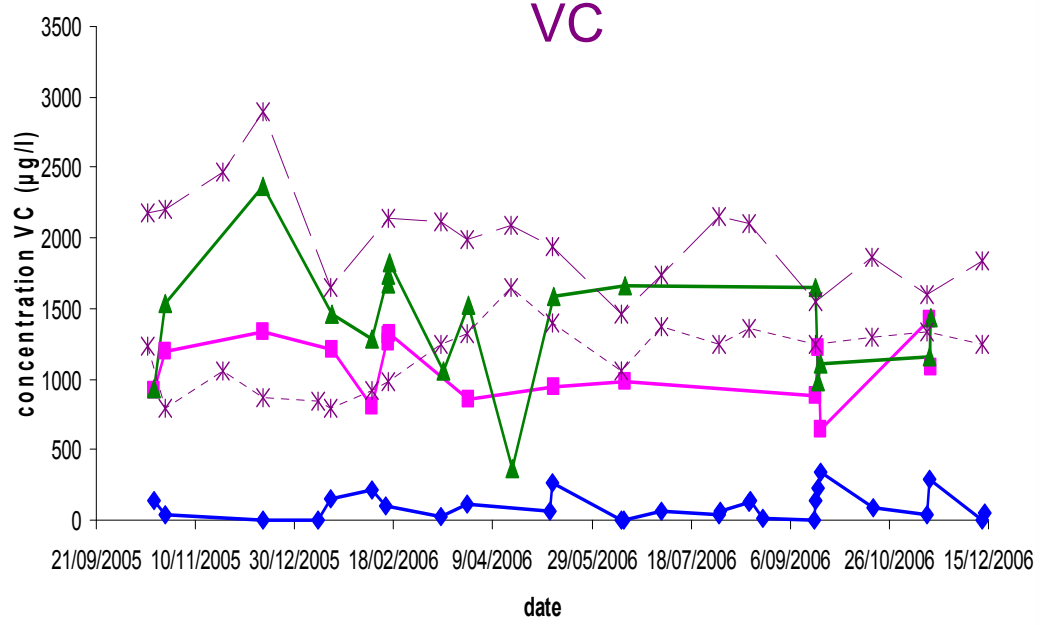
SS 24,5 m upstream from post 26

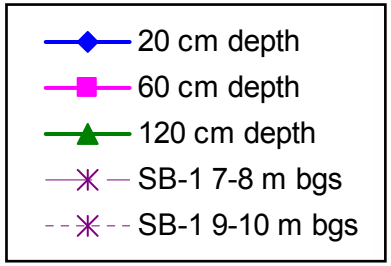


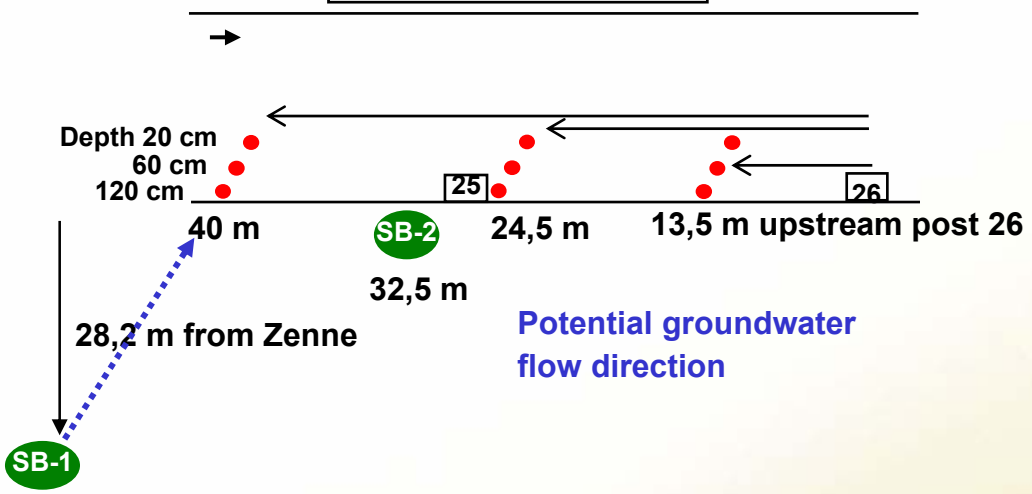
SS 13,5 m upstream from post 26

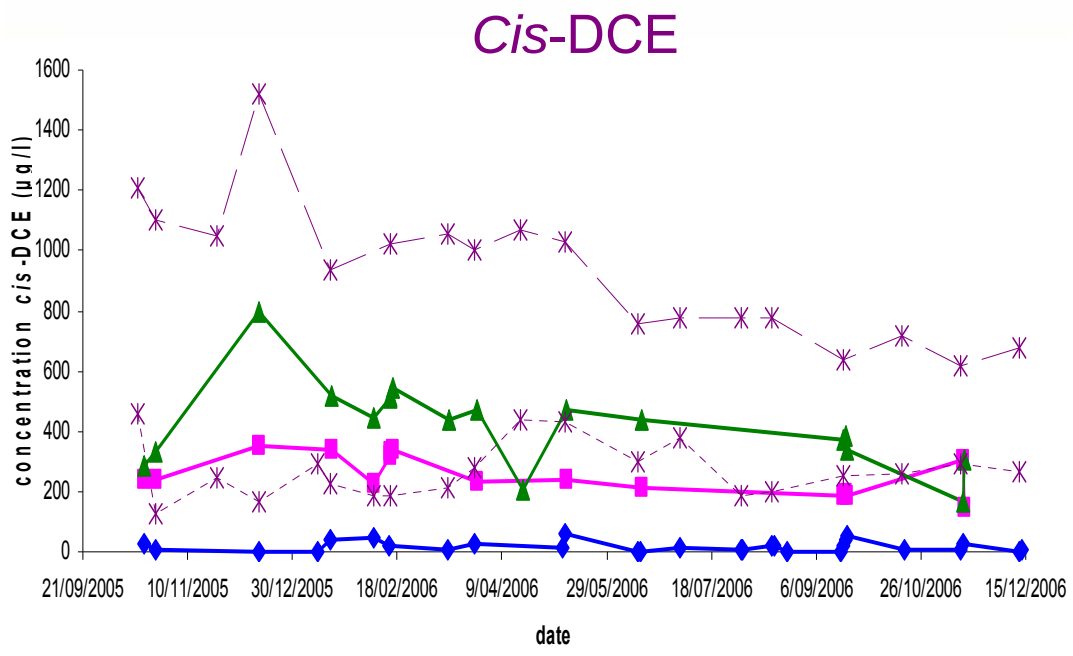


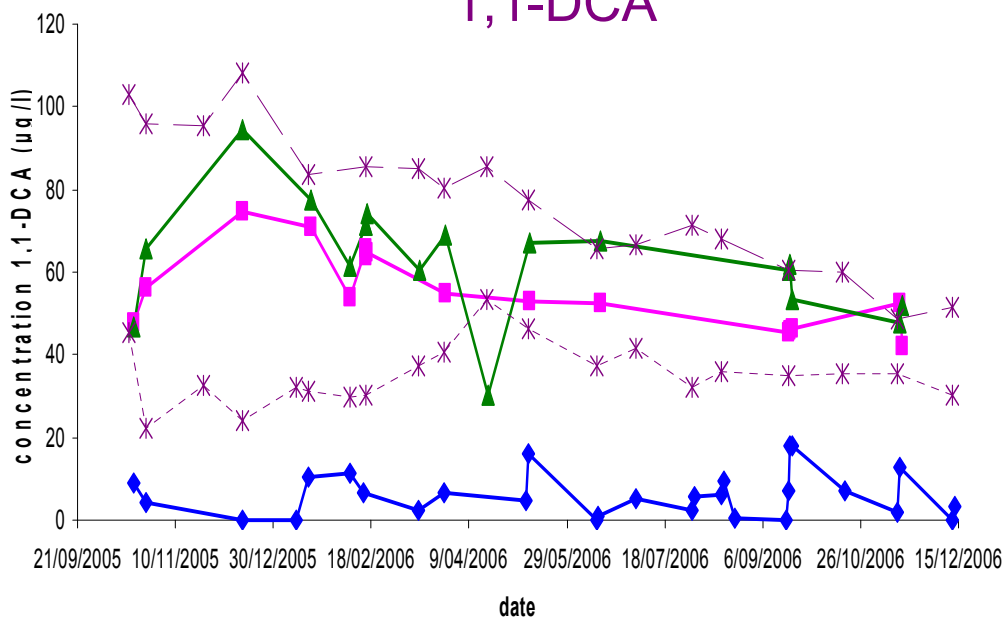
Pore water at 40 m upstream post 26 ↔ groundwater at SB-1









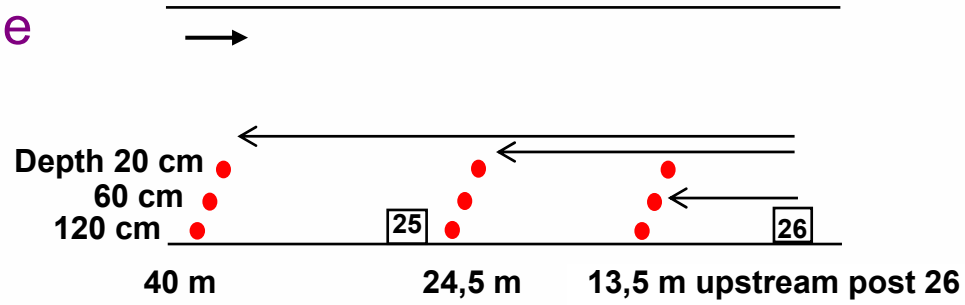


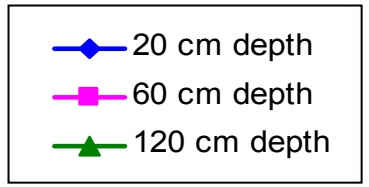
In situ monitoring of physico-chemical parameters
Teflon pore water samplers

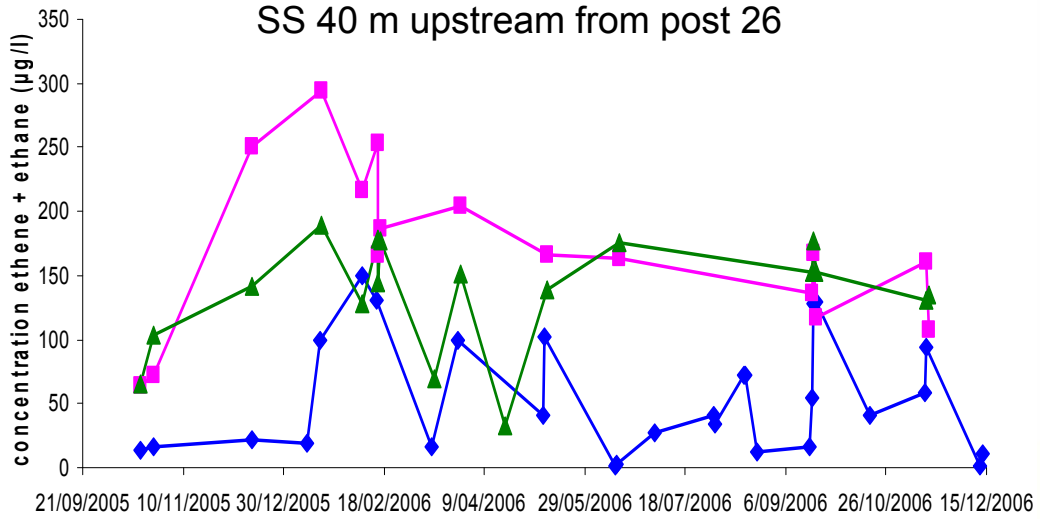
$$[CAH]_{20\ cm\ depth} < \underbrace{[CAH]_{60\ cm\ depth} \leq [CAH]_{120\ cm\ depth}}_{\sim [CAH]_{inflowing\ groundwater}}$$

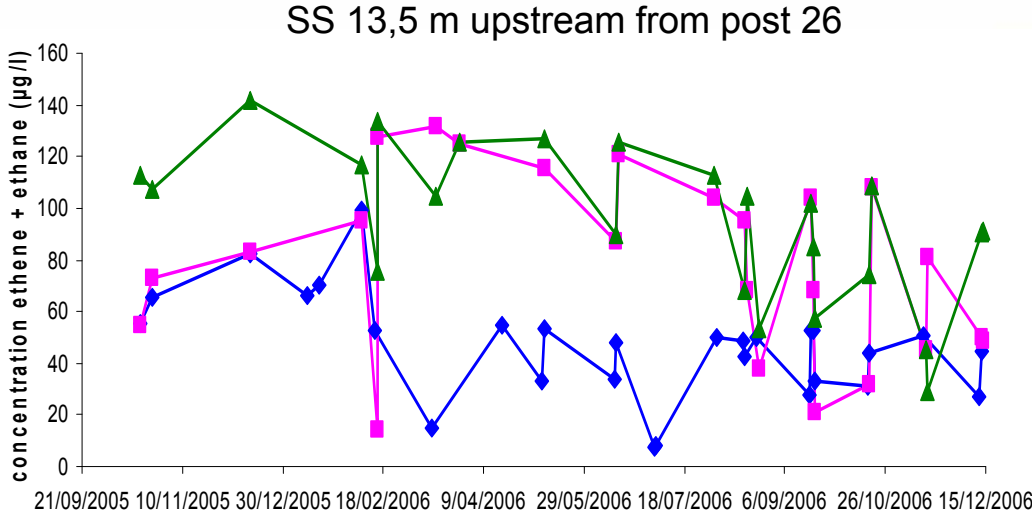
- Microbial degradation?
- Dilution by surface water?

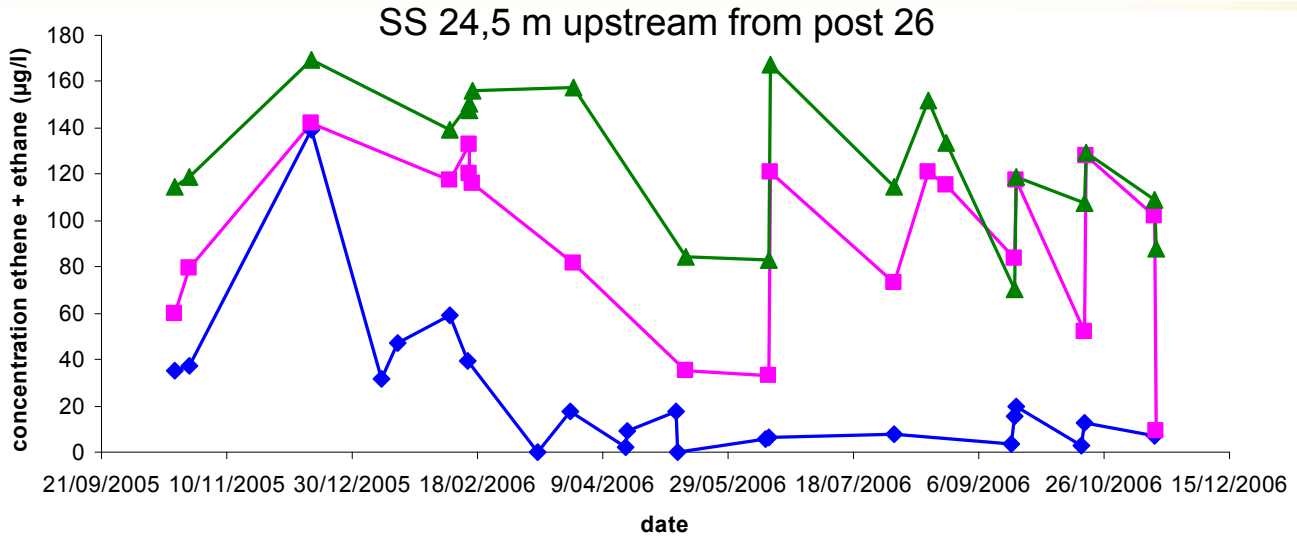
ethene + ethane











In situ monitoring of physico-chemical parameters
Teflon pore water samplers

$$[CAH]_{20\ cm\ depth} < [CAH]_{60\ cm\ depth} \leq [CAH]_{120\ cm\ depth}$$

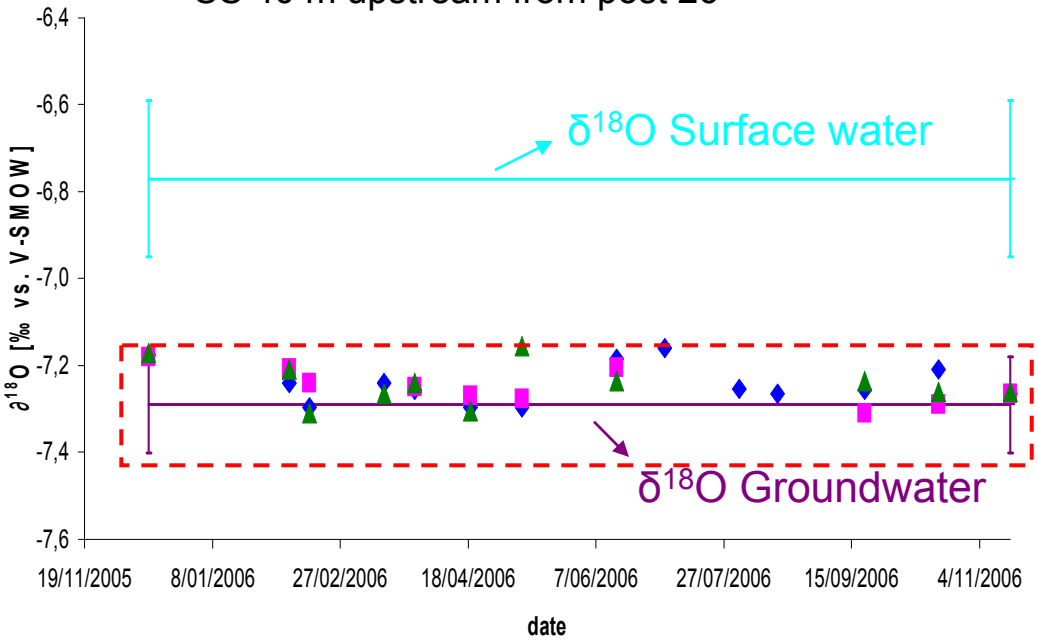
- Microbial degradation?

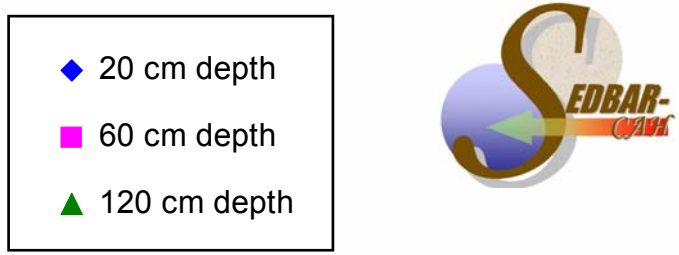
  Ethene + ethane also lowest at 20 cm depth

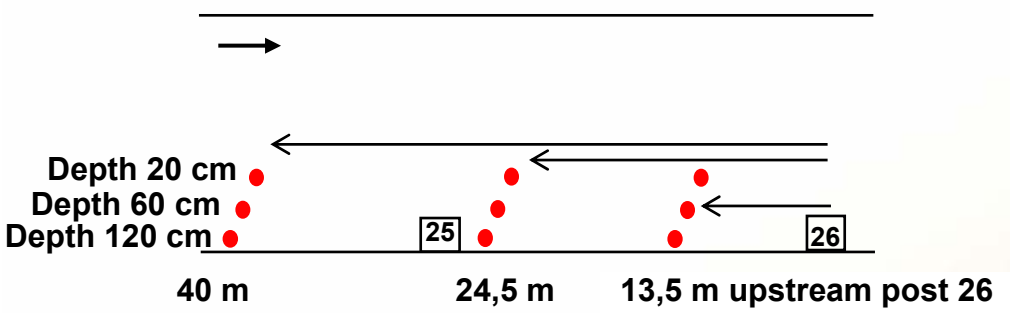
- Dilution by surface water?

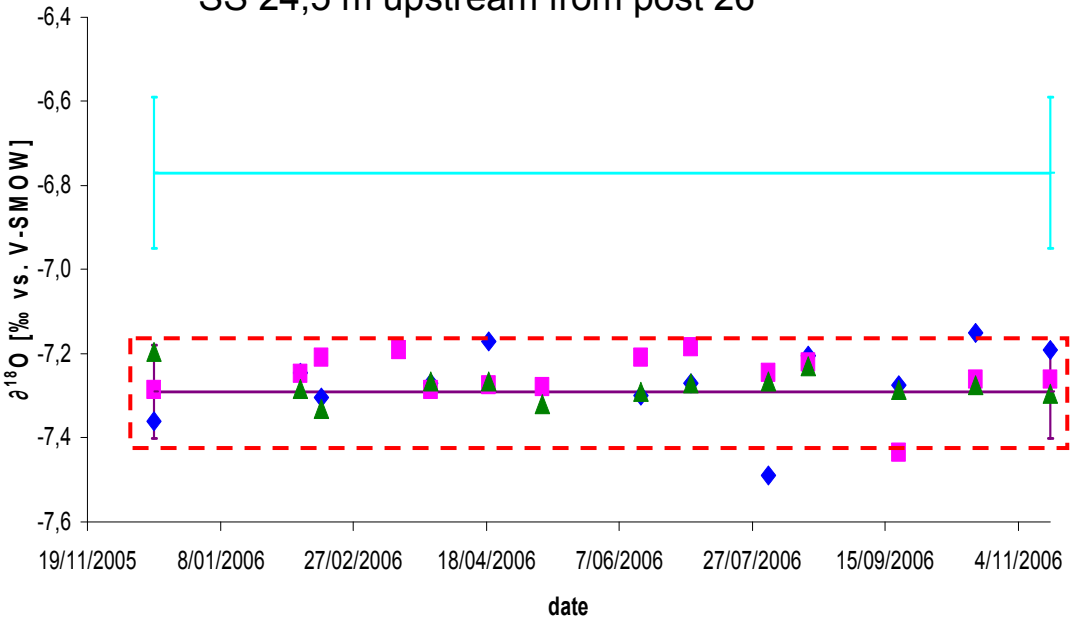
  → investigation by H&O isotope analyses

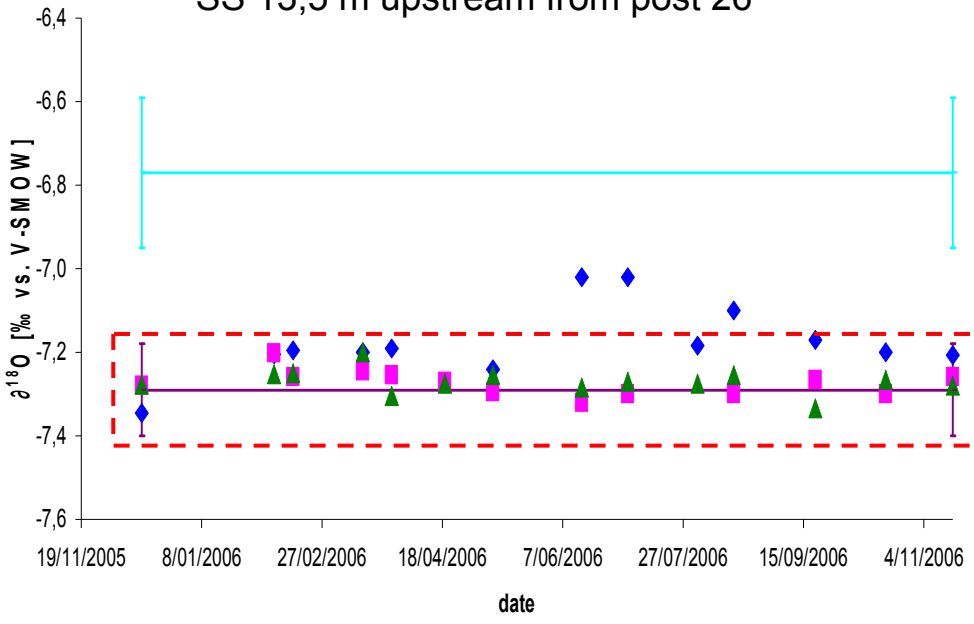
$\delta^{18}O$


SS 40 m upstream from post 26
δ18O Surface water
δ18O Groundwater
∂18O [‰ vs. V-SMOW]
-6,4
-6,6
-6,8
-7,0
-7,2
-7,4
-7,6
19/11/2005
8/01/2006
27/02/2006
18/04/2006
7/06/2006
27/07/2006
15/09/2006
4/11/2006
date


20 cm depth
60 cm depth
120 cm depth


Depth 20 cm
Depth 60 cm
Depth 120 cm
25
26
40 m
24,5 m
13,5 m upstream post 26


SS 24,5 m upstream from post 26
∂18O [‰ vs. V-SMOW]
-6,4
-6,6
-6,8
-7,0
-7,2
-7,4
-7,6
19/11/2005
8/01/2006
27/02/2006
18/04/2006
7/06/2006
27/07/2006
15/09/2006
4/11/2006
date


SS 13,5 m upstream from post 26
∂18O [‰ vs. V-SMOW]
-6,4
-6,6
-6,8
-7,0
-7,2
-7,4
-7,6
19/11/2005
8/01/2006
27/02/2006
18/04/2006
7/06/2006
27/07/2006
15/09/2006
4/11/2006
date

Evaluation of CAH degradation potential of the sediment microbial community ↔ aquifer upstream

A. Detection of:
   1) **dechlorinating bacteria**
   2) **dehalogenase genes**
   on DNA level by
   Polymerase Chain Reaction

Presence ?

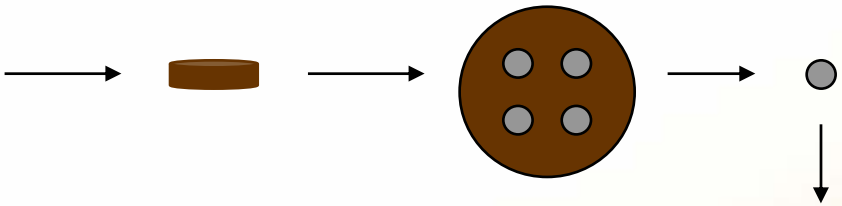
B. Anaerobic column degradation tests

Activity ?

Evaluation of CAH degradation potential

A. PCR detection of dechlorinating bacteria and VC dehalogenase genes

SEDIMENT SAMPLES



DNA extraction

total DNA

PCR amplification

Amplified fragments

Agarose gel

Evaluation of CAH degradation potential

A. PCR detection of dechlorinating bacteria and VC dehalogenase genes

Depth (cm)	*Dehalococcoides*	*bvc* A gene	*vcr* A gene
1	+	+	+
2	+	-	+
3	+	+	+
4	+	+	-
4,4	+	+	+
5	+	+	+
6	+	+	+
7	+	+	+
8	+	+	+
9	+	+	+
9,4	+	+	+
10	+	+	+
14	+	+	+
18	+	+	-
24	+	+	+
29	+	+	+
34	-	-	-
38	-	-	-
43	+	+	+
47	-	-	-
52	-	-	-
56	+	+	+
61	-	-	-
65	-	-	-

- *Dehalococcoides* species:

PCE→ TCE→ DCE→ VC→ ethene

- *Dehalococcoides* sp. strain BAV1:

PCE→ TCE→ DCE→ VC→ ethene

↓

*bvc*A gene

(DCE, VC are growth supporting)

- *Dehalococcoides* sp. strain VS:

PCE→ TCE→ DCE→ VC→ ethene

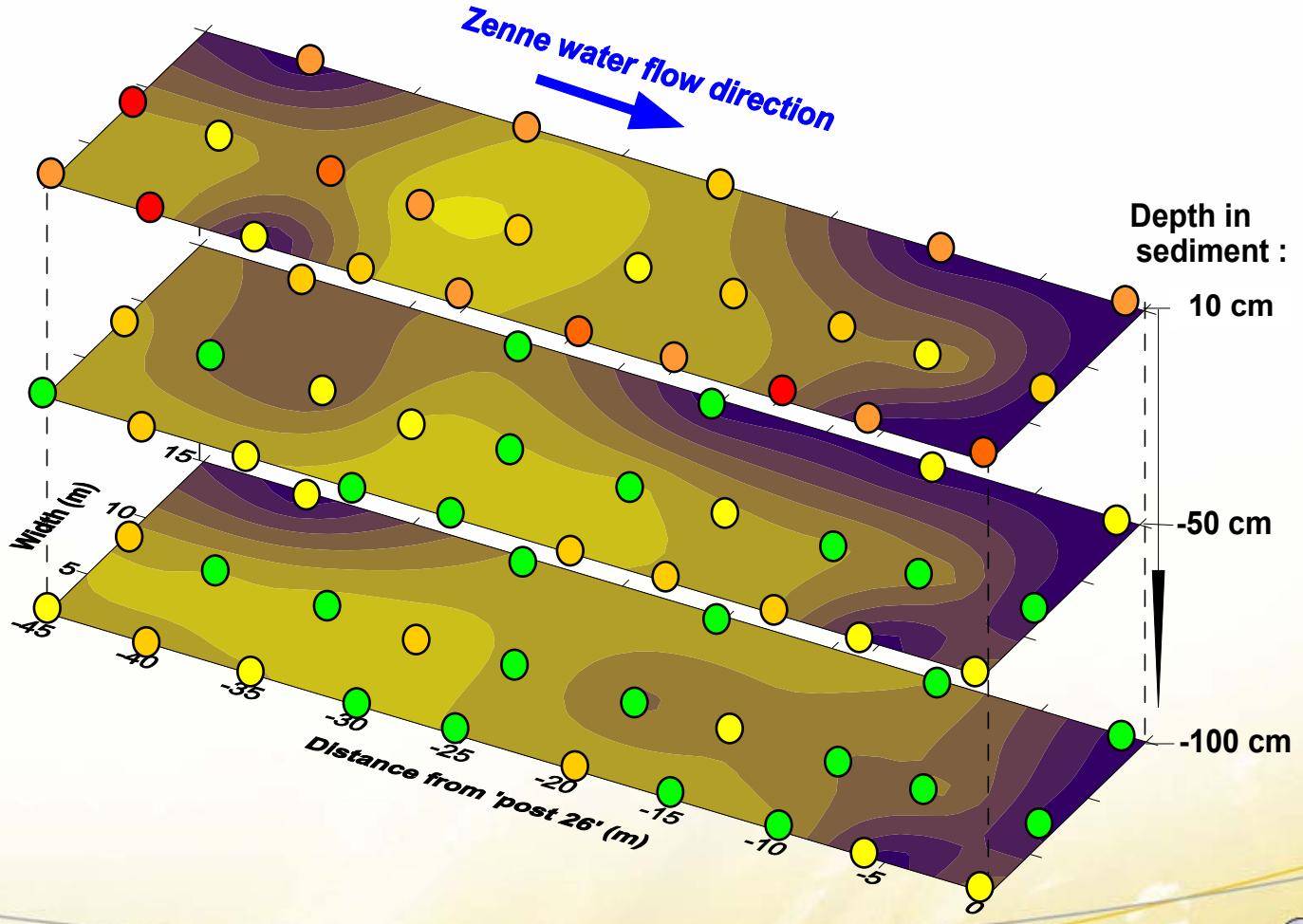
↓

*vcr*A gene

(TCE, DCE, VC are growth supporting)

CAH degradation potential: presence?

A. Detection/quantification of *Dehalococcoides* sp.



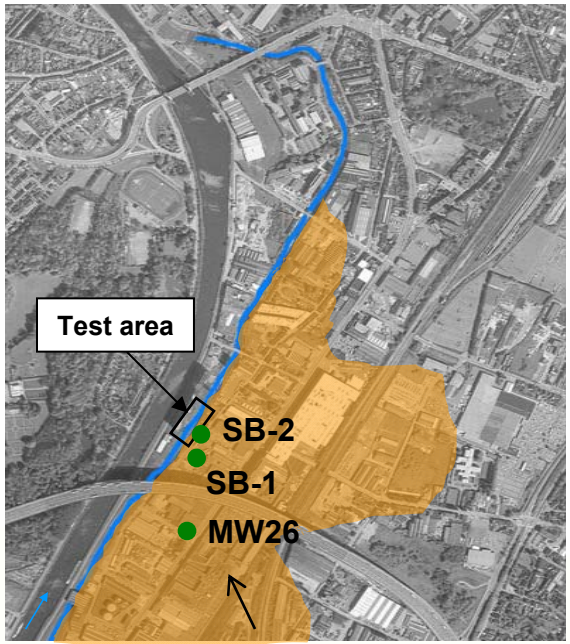
16S rRNA gene copies / gr sediment

- 10^5 - 10^6
- 10^4 - 10^5
- 10^3 - 10^4
- 10^2 - 10^3
- 10^1 - 10^2
- 0 - 10^1

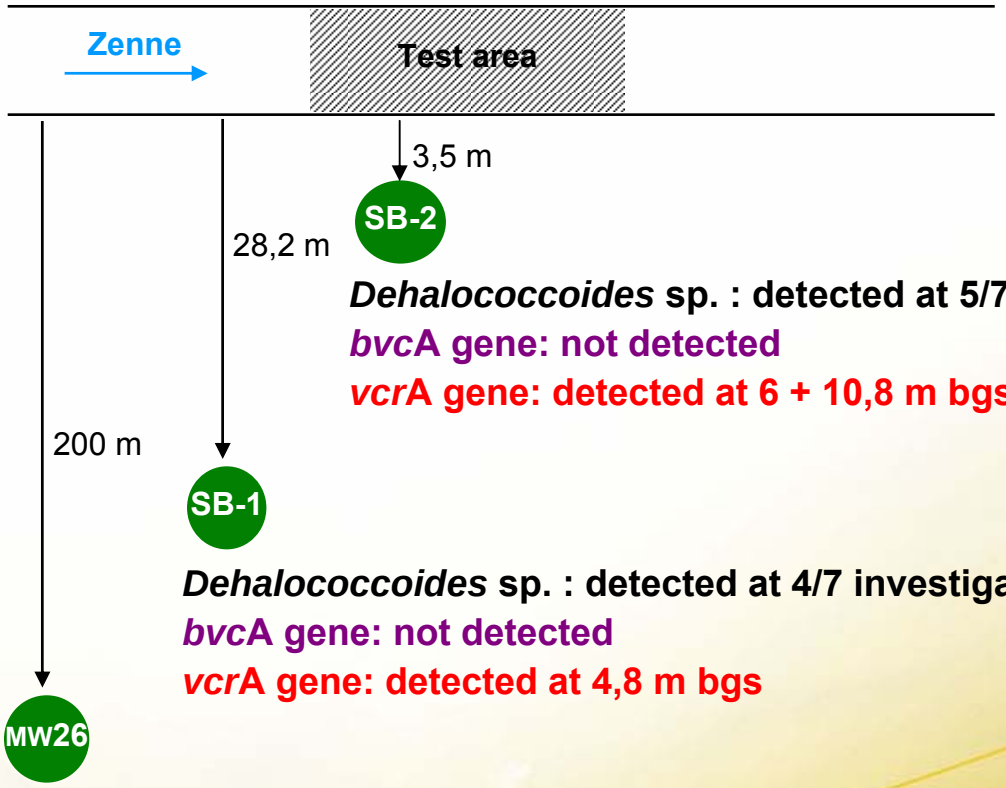
Evaluation of CAH degradation potential

A. PCR detection of dechlorinating bacteria and VC dehalogenase genes

AQUIFER SAMPLES



- SB-2: 3,6-10,8 m bgs (each 1,2 m)
- SB-1: 3,6-10,8 m bgs (each 1,2 m)
- MW26: 0-8 m bgs (each 1 m)



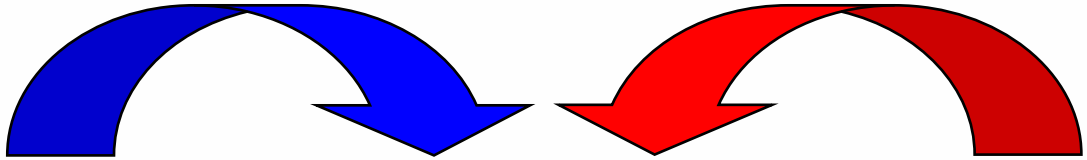
***Dehalococcoides* sp. : detected at 5/7 ≠ depths**
***bvc*A gene: not detected**
***vcr*A gene: detected at 6 + 10,8 m bgs**

***Dehalococcoides* sp. : detected at 4/7 investigated depths**
***bvc*A gene: not detected**
***vcr*A gene: detected at 4,8 m bgs**

***Dehalococcoides* sp. : detected at 3/9 investigated depths**
***bvc*A gene: not detected**
***vcr*A gene: detected at 7 m bgs**

CAH degradation potential: Activity?

B. Anaerobic batch/column degradation tests



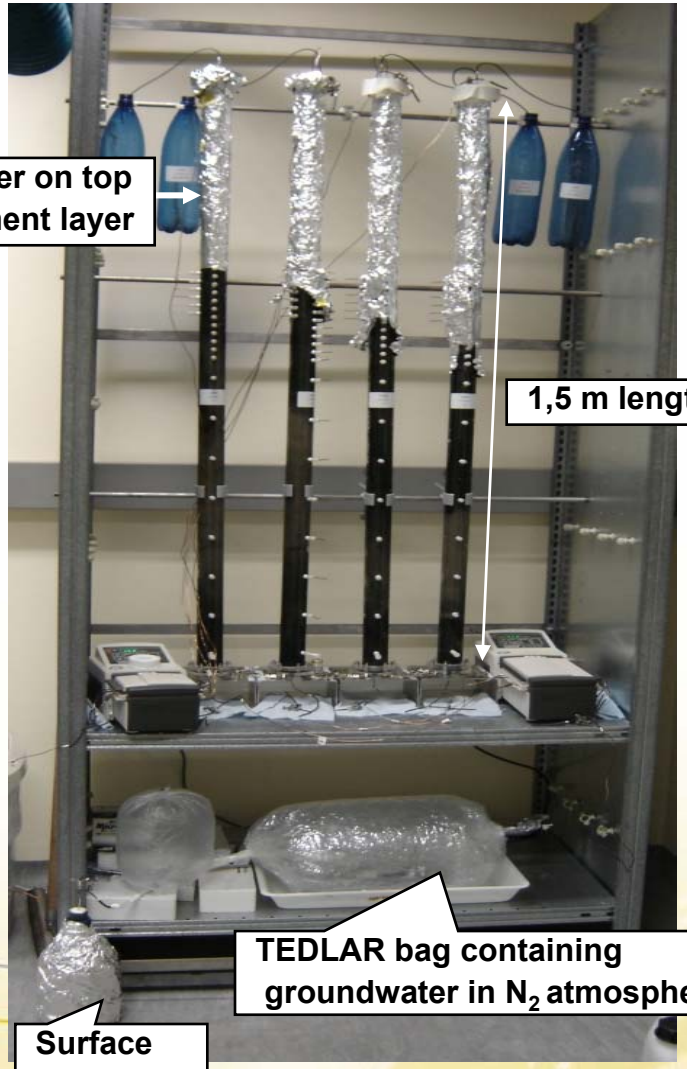
Zenne sediment

Anaerobic medium
+ VC (2 ppm)

Evaluation of CAH degradation potential

B. Anaerobic column degradation tests

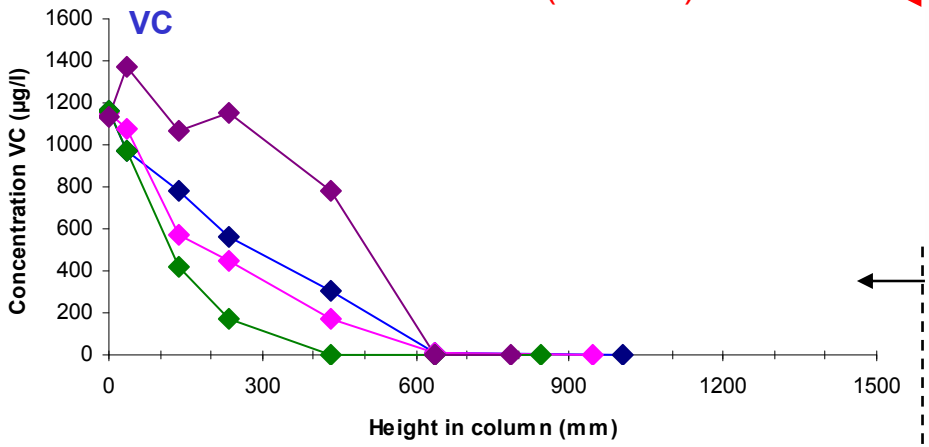
SEDIMENT COLUMNS

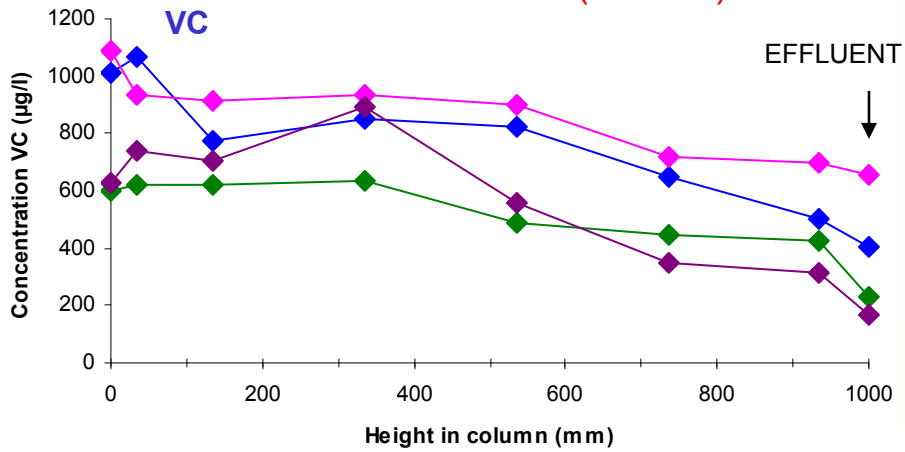


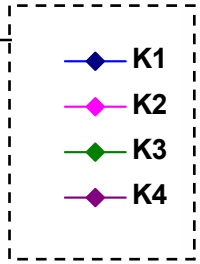
AQUIFER COLUMNS

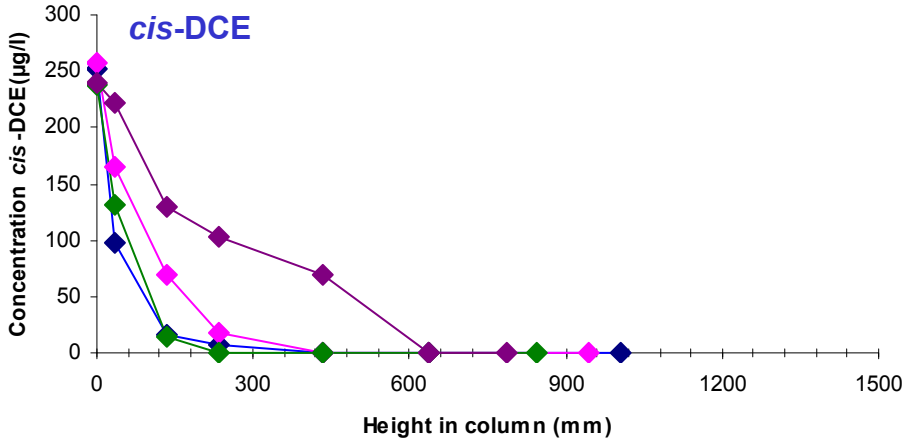
SEDIMENT COLUMNS (Dec '06)

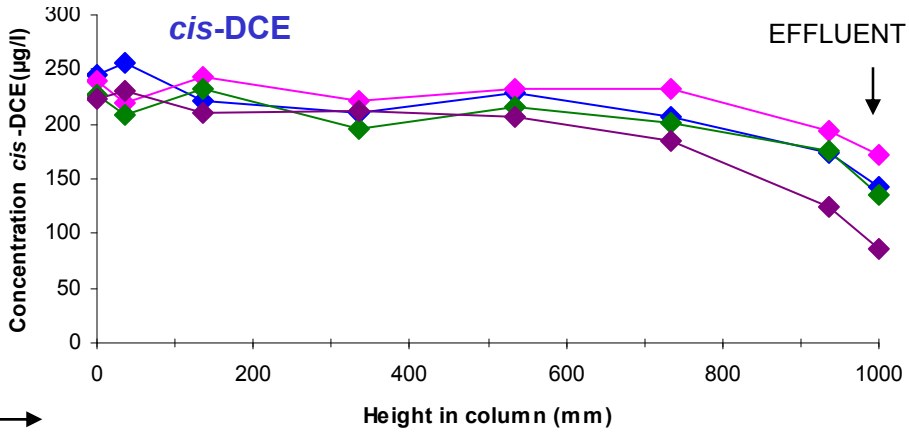
AQUIFER COLUMNS (Dec '06)

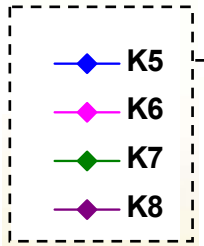


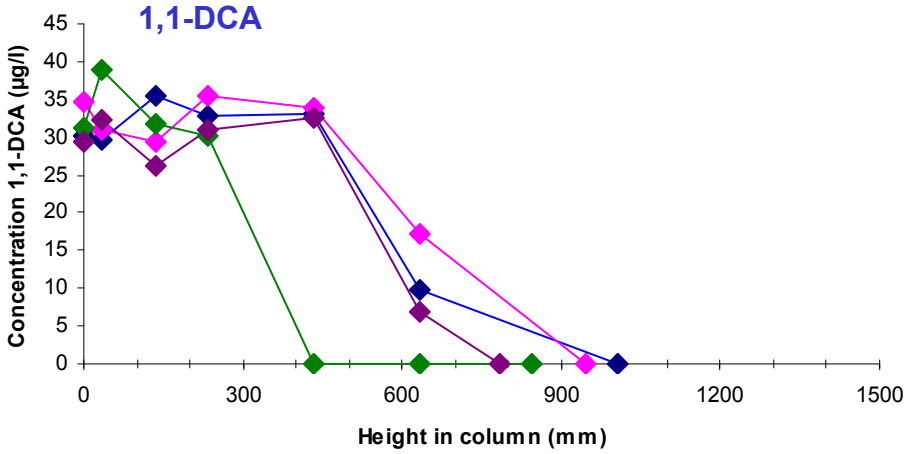


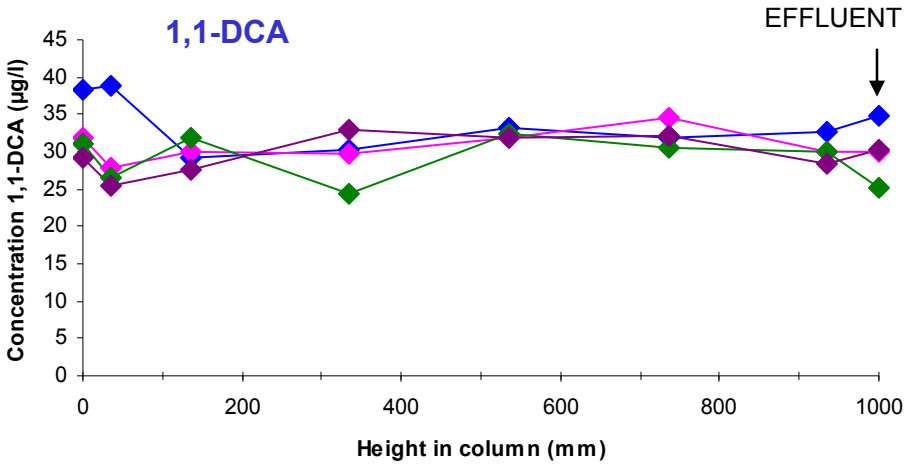








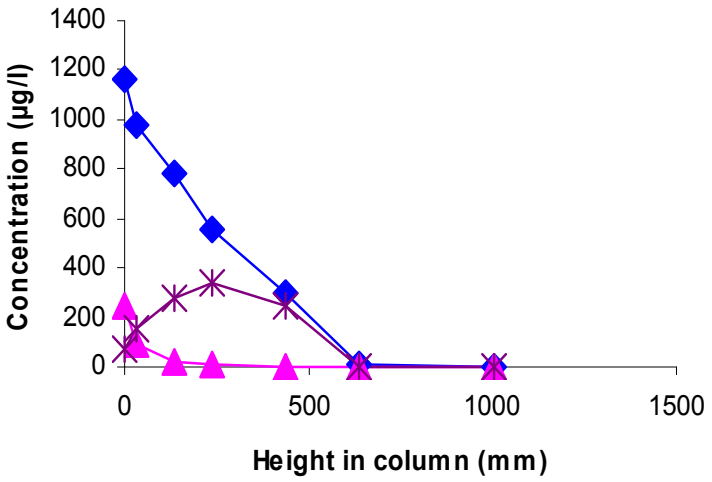




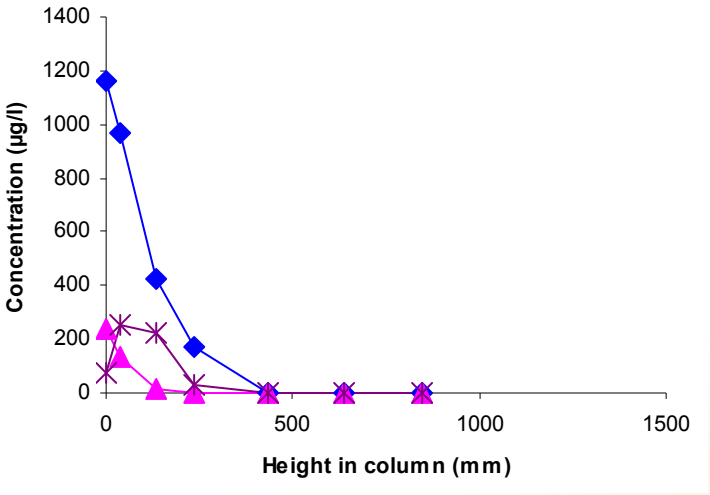
Evaluation of CAH degradation potential

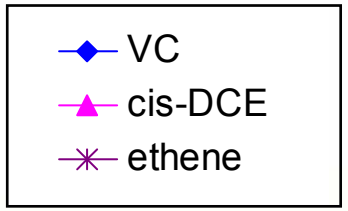
B. Anaerobic column degradation tests: SEDIMENT COLUMNS

K 1

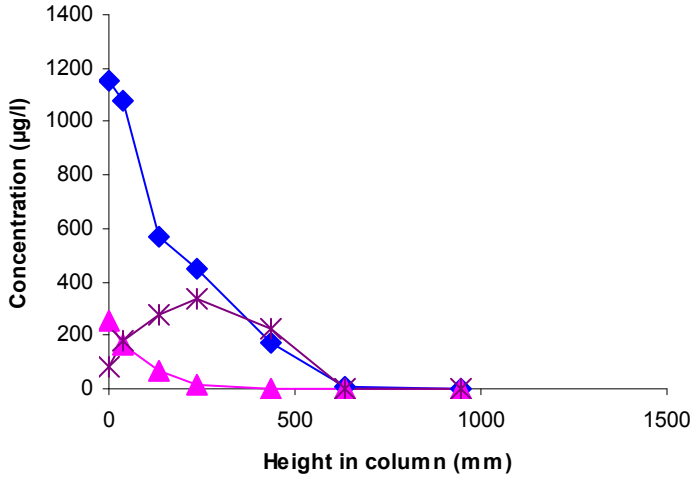


K 3

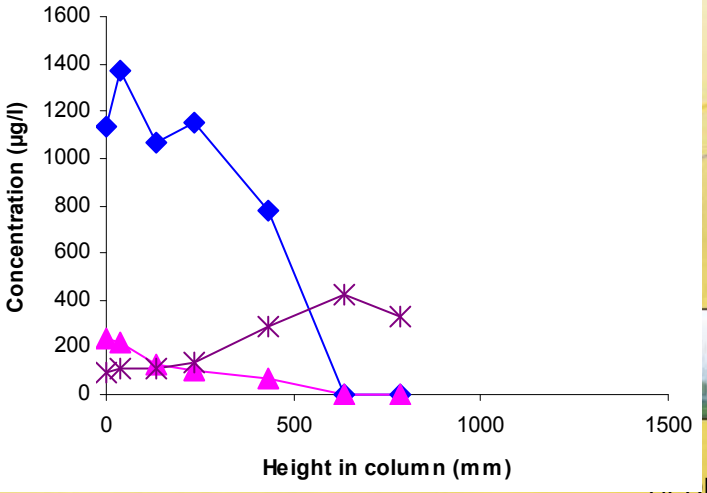




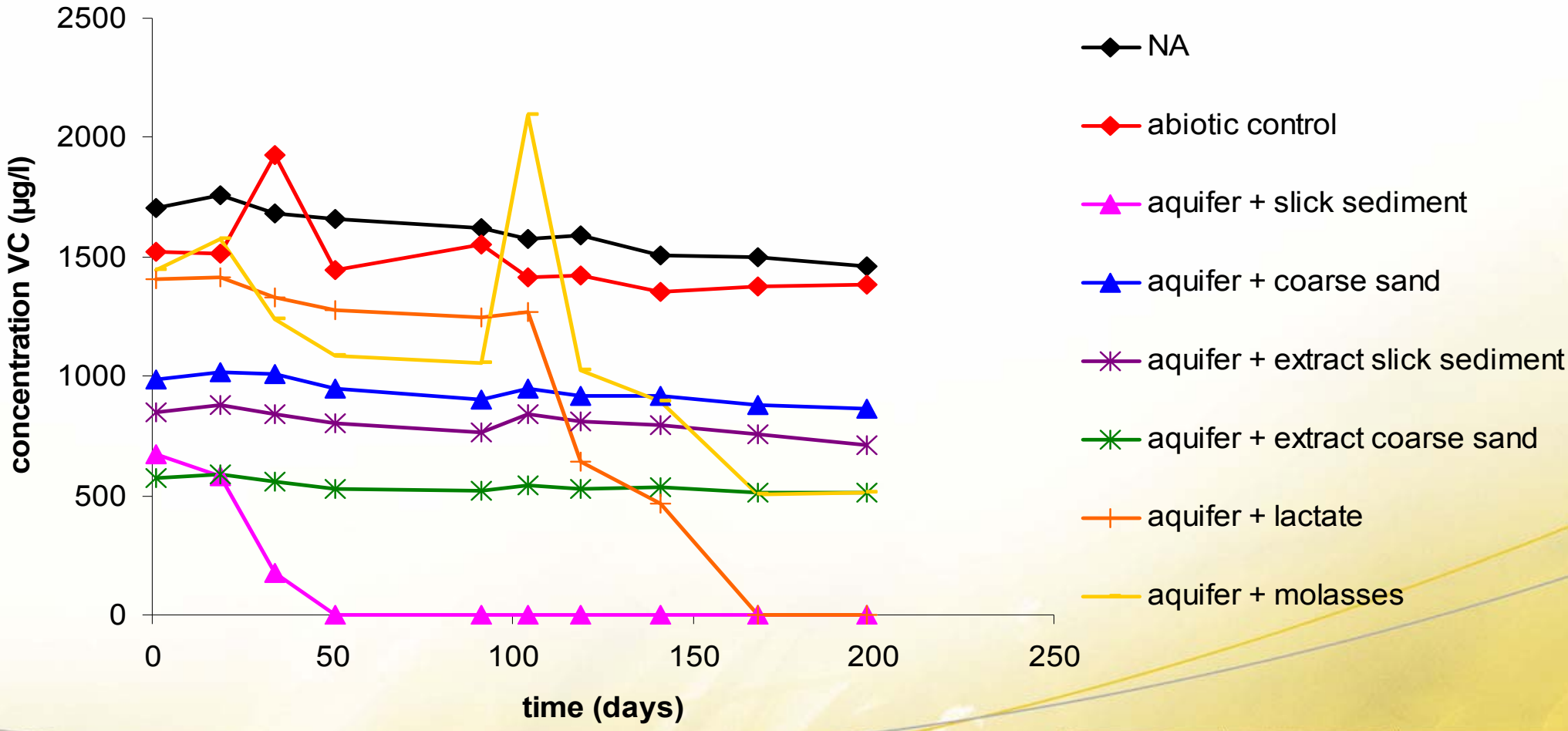
K 2



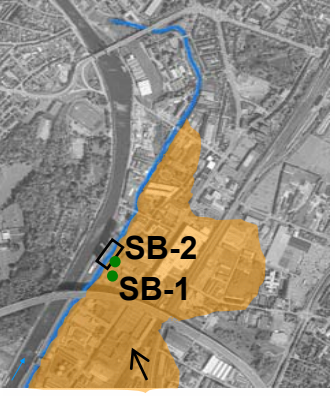
K 4



CAH degradation potential in aquifer: Activity?



Sampling of monitoring wells



26/10/05

[VC]
[*cis*-DCE]
[1,1-DCA]
[ethene + ethane]
(in µg/l)

	20 cm	60 cm	120 cm
[VC]	126	724	944
[*cis*-DCE]	<d	<d	<d
[1,1-DCA]	59	125	124
[ethene + ethane]	38	80	119

24,5 m
26
40 m
SB-2
32,5 m
Zenne
7 m
SB-1

	20 cm	60 cm	120 cm
[VC]	2640	2109	2200
[*cis*-DCE]	<d	<d	1203
[1,1-DCA]	268	252	96
[ethene + ethane]	289	254	293

Coarse sand

	20 cm	60 cm	120 cm
[VC]	35	1197	1532
[*cis*-DCE]	<d	237	333
[1,1-DCA]	<d	56	66
[ethene + ethane]	16	72	104

Coarse sand/gravel

[VC]	796
[*cis*-DCE]	128
[1,1-DCA]	22
[ethene + ethane]	124

Conclusions

- CAH degradation potential present

  → Sediment: potential **natural biobarrier** for infiltrating groundwater pollutants

  BUT: *in situ* [VC] concentrations > Belgian sanitation norm

- Stimulation of CAH degradation necessary
  - → sediment
  - → aquifer upstream of the river → OK by adding C-source or sediment(-extract)

With thanks to

VITO





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