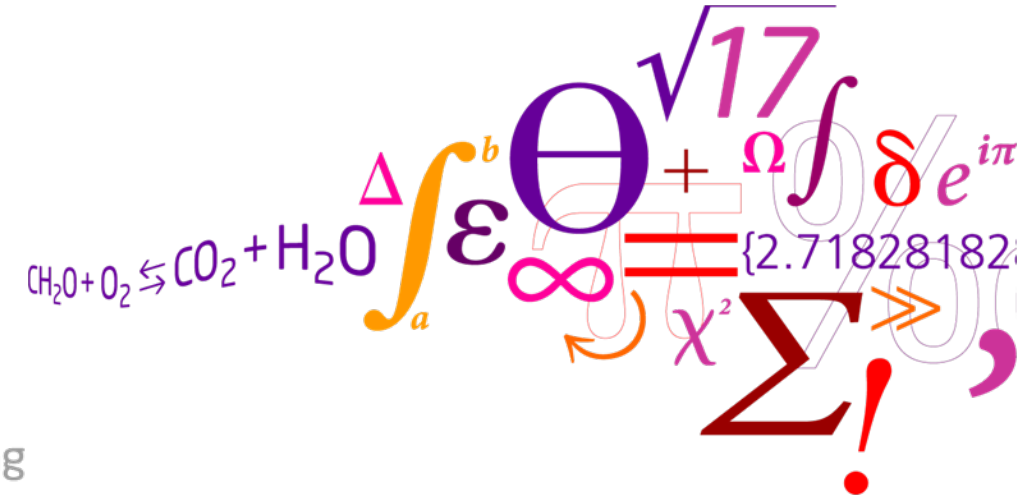
Technical University of Denmark

Why we need upscaling to describe microbiological processes in groundwater: Examples from fractured porous media and bioaugmentation technologies

P.J. Binning



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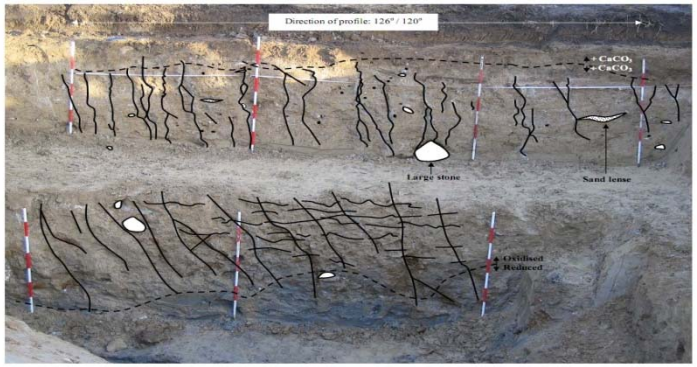
Department of Environmental Engineering

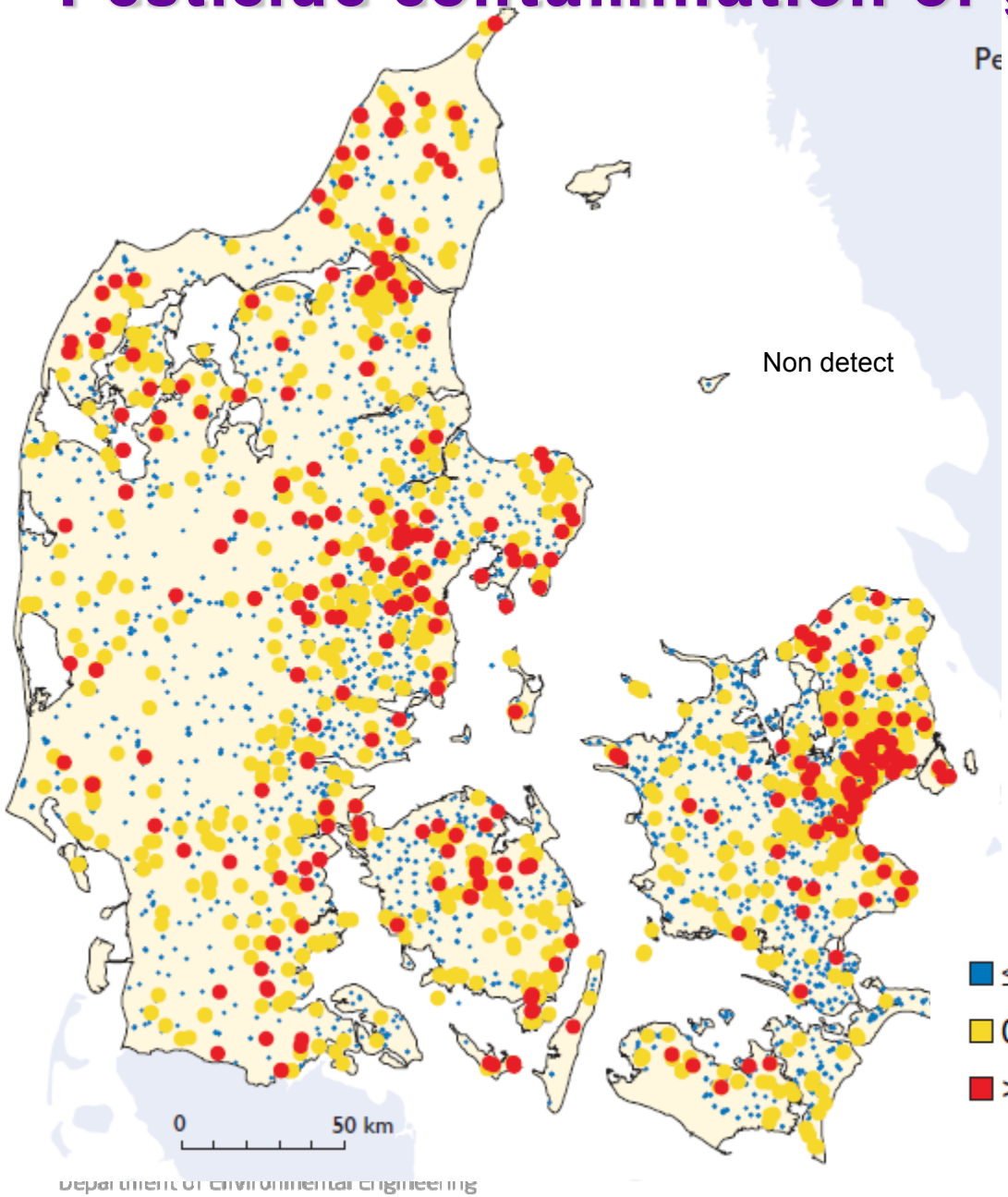
Two problems where upscaling is needed

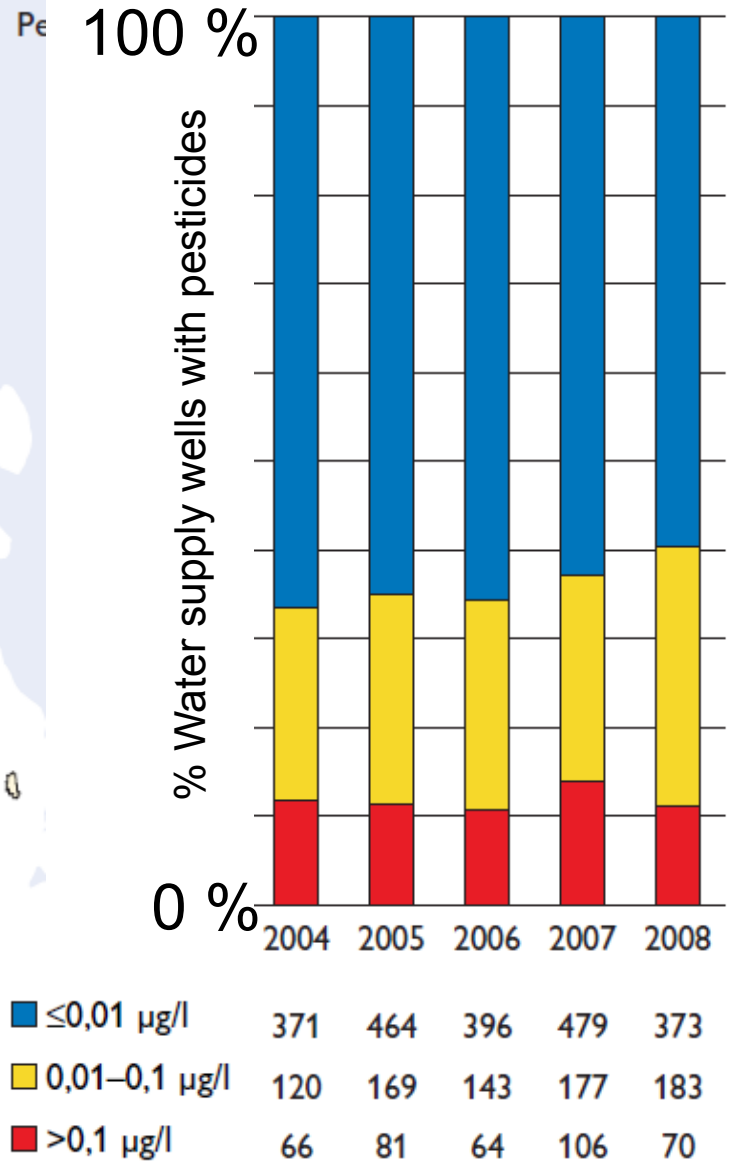
Bioaugmentation

Enhanced biodegradation in clays



Pesticide contamination of groundwater





GEUS, 2006, 2009

Bioaugmentation

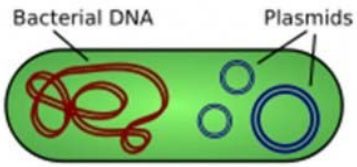
"the technique for improvement of the capacity of a contaminated matrix (...) to remove pollution by the introduction of specific competent strains or consortia of microorganisms"
(El Fantroussi and Agathos, Curr. Opin. Microbiol. 2005)

Shimidzu et al. 2002

liquid microbial culture

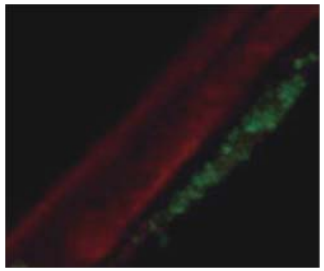
activated soil

immobilized microbes



microbes with mobile genes

Boldt et al. 2004

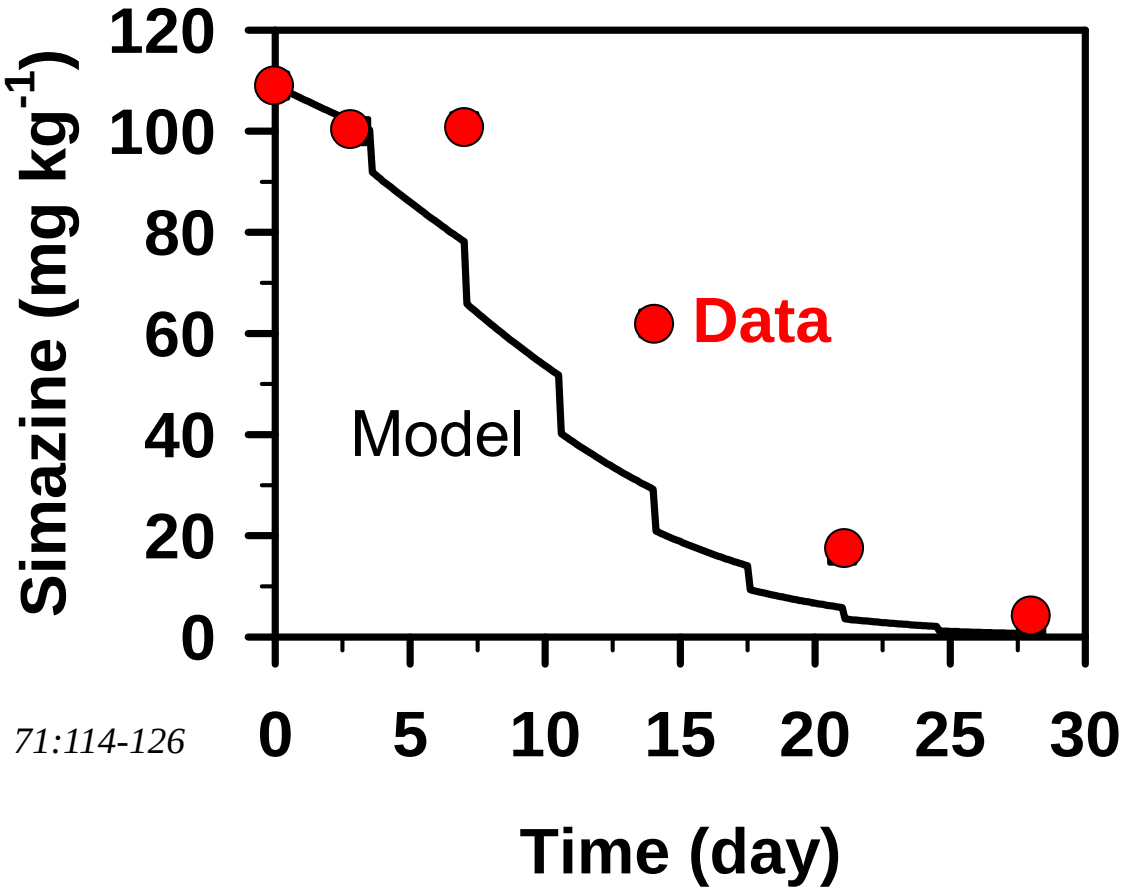


rhizosphere biaogumentation

phyto-augmentation

Immobilized microbes

- *simazine, agricultural soil*
- *50% water saturation*
- *2-mm alginate beads*
- *Pseudomonas* sp. MHP41

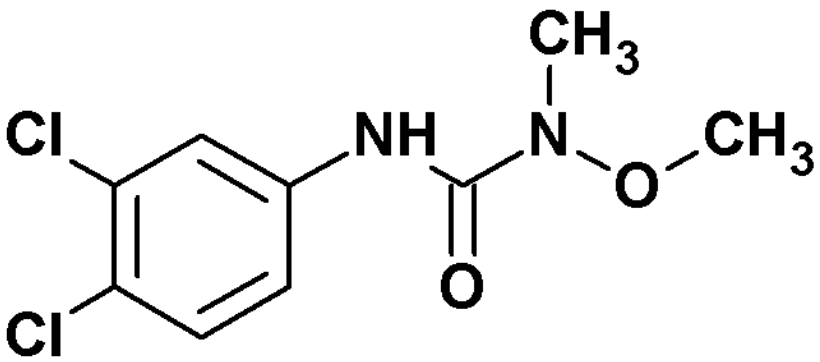


Morgante et al. (2010) FEMS Microbiol. Ecol. 71:114-126

Linuron

Herbicide used since 1965, now banned in 7 of 27 EU countries

Suspected developmental or reproductive toxin



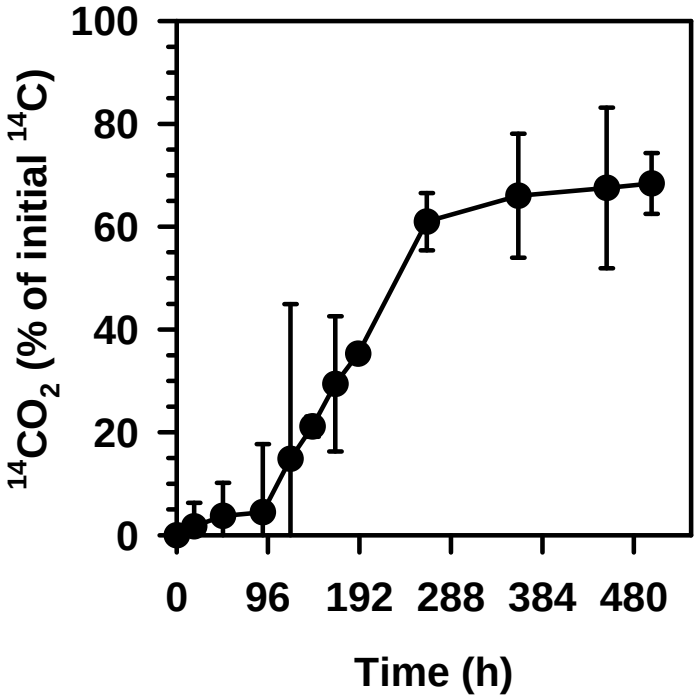
linuron

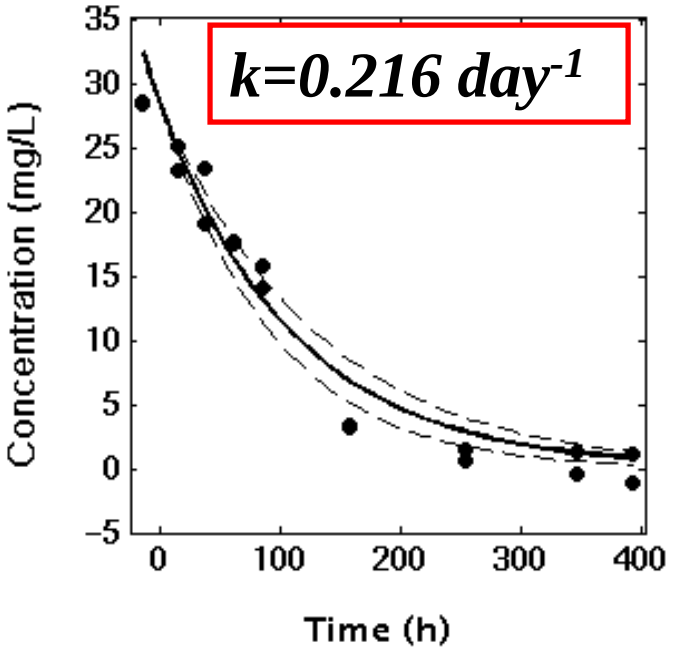
500 g/Kg linuron
in the form of a water dispersible granule

First-order mineralization rate

$$C = C_0 \exp(-kt)$$

Variovorax sp. SRS16

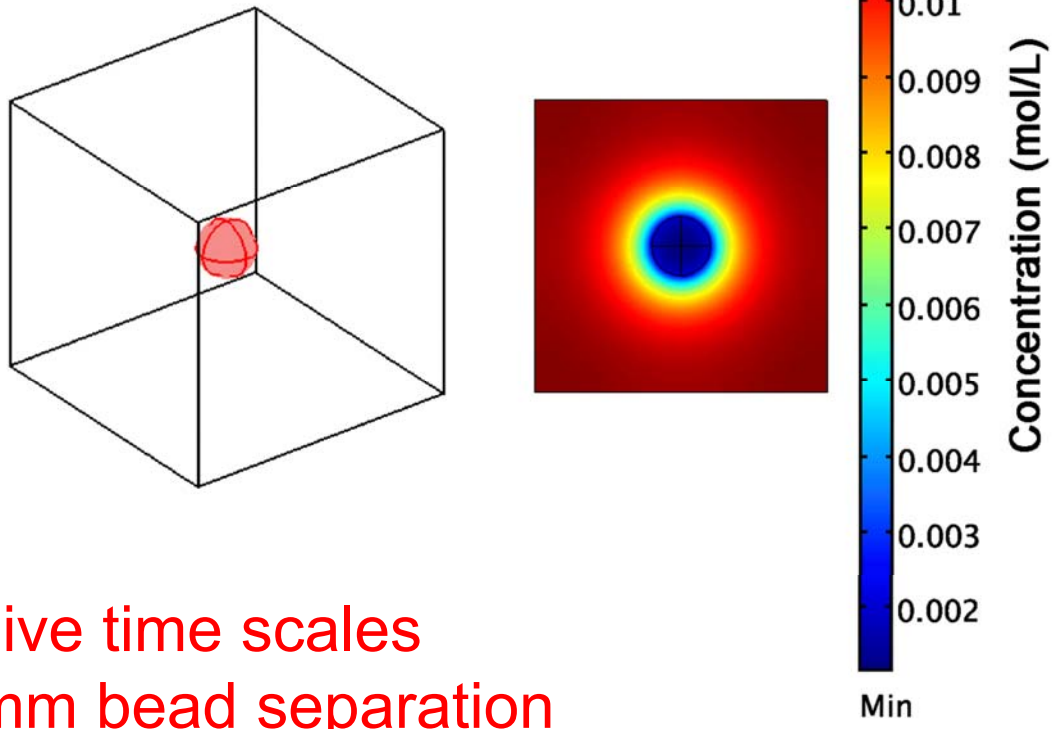




Reaction time scales about 5 days

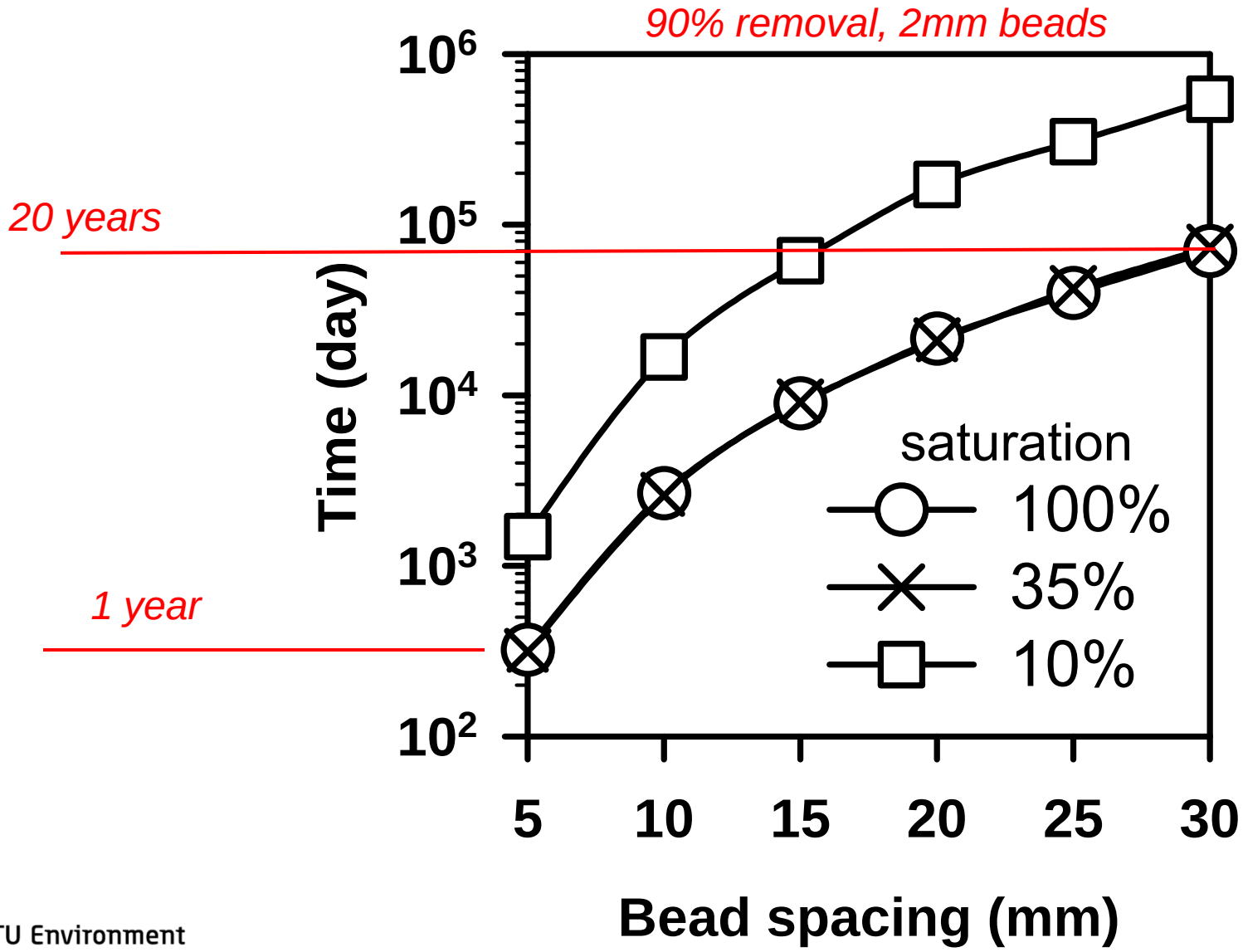
Diffusive transport

$$\frac{\partial(\theta_w + K_H\theta_a)C_w}{\partial t} - \nabla \bullet (\theta_w \mathbf{D_w} + K_H\theta_a \mathbf{D_a})\nabla C_w + \theta_w k C_w = 0$$



Expected diffusive time scales
17 days for 20mm bead separation

Mineralization time scale



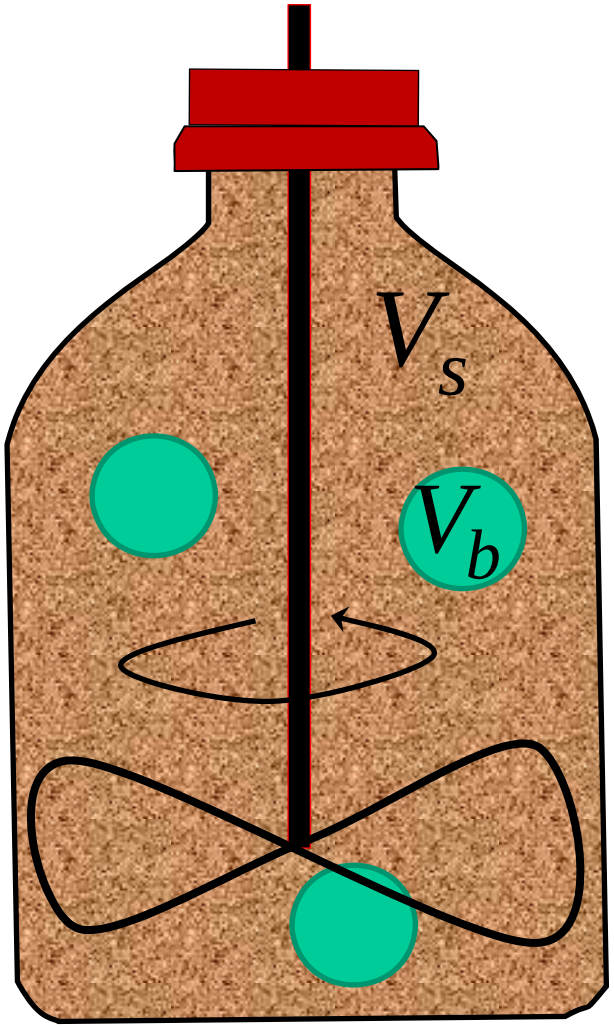
A simple mixing model

$$\frac{dm}{dt} = -k_b \frac{m\theta_{w,b}V_b}{V_b + V_s} - k_s \frac{m\theta_{w,s}V_s}{V_b + V_s} = -k_{eff}\, m$$

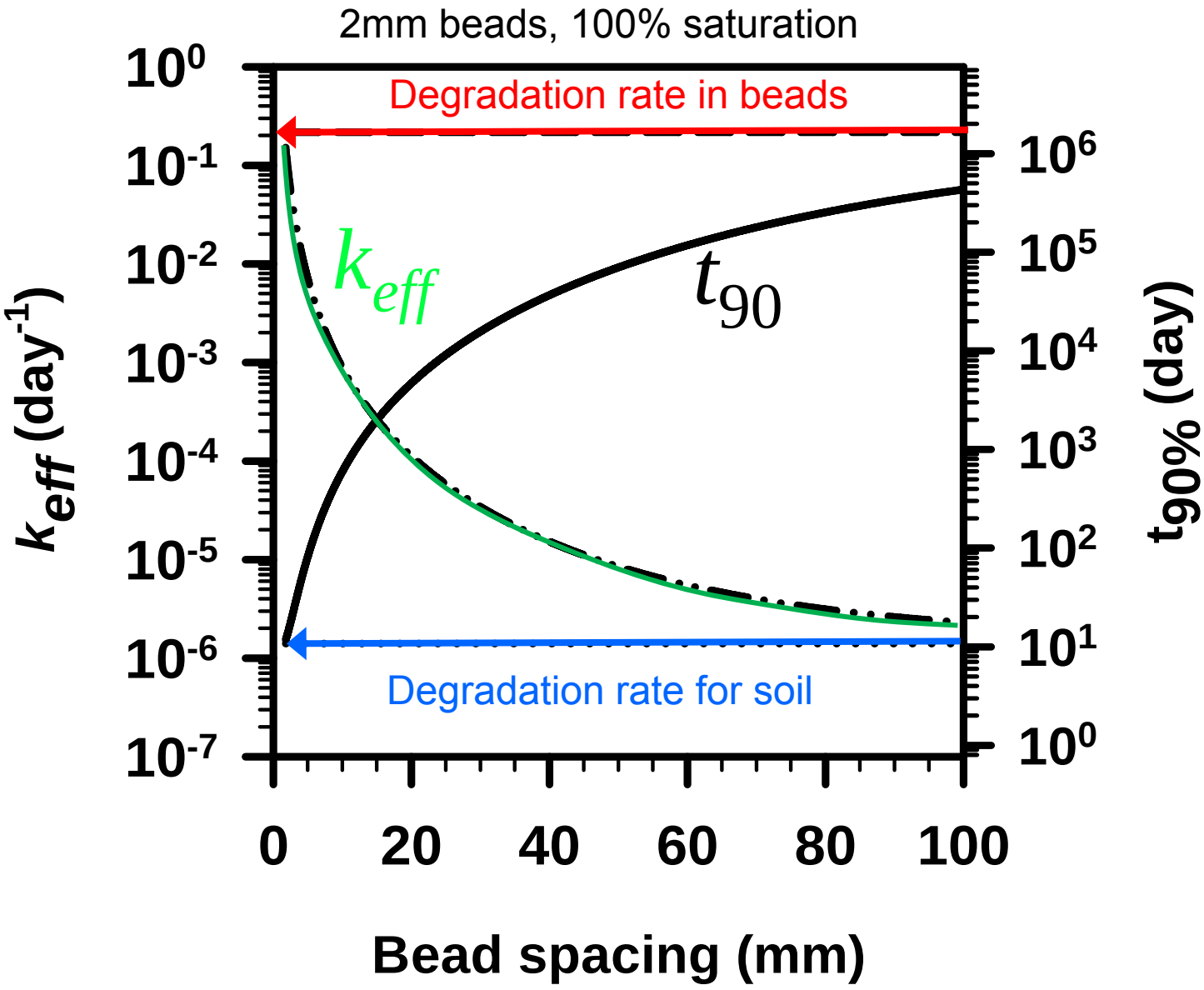
$$k_{eff} = \frac{\theta_{w,b}k_bV_b + \theta_{w,s}k_sV_s}{V_b + V_s}$$

$$m = m_0 \exp\left(-k_{eff}\, t\right)$$

For $V_b/(V_s+V_b)=1\%$
reaction rate reduced by a factor of 100



Simple mixing model



Application of technology

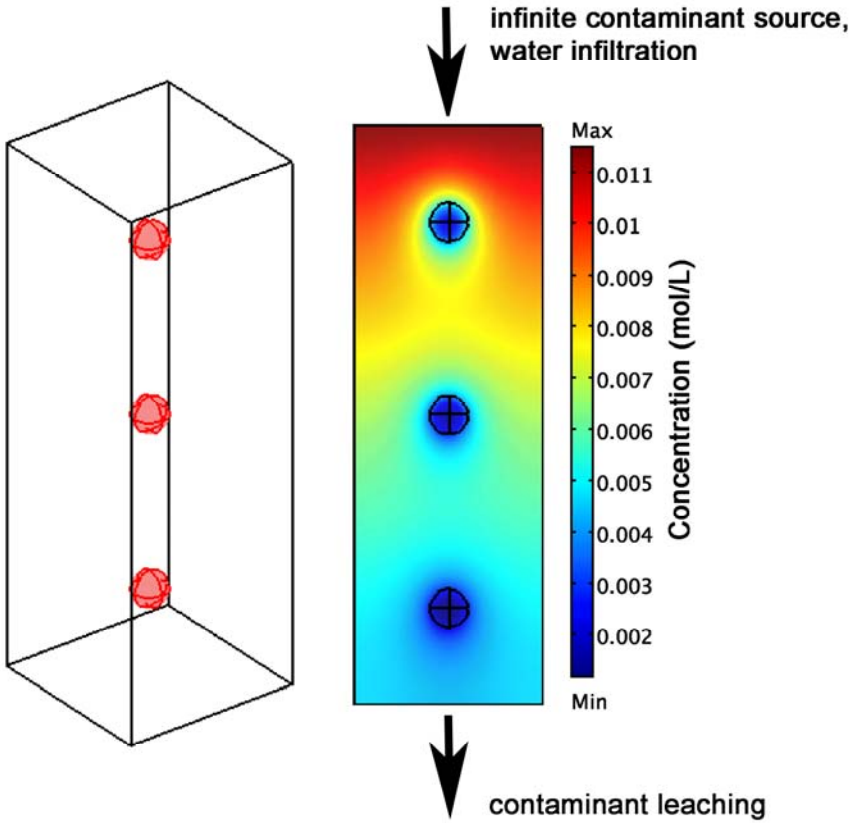
Require **~24 tons 2mm beads** for **1 ha** to remove 90% linuron in 100 days

(spaced at **<10 mm** in a layer of **100 mm)**

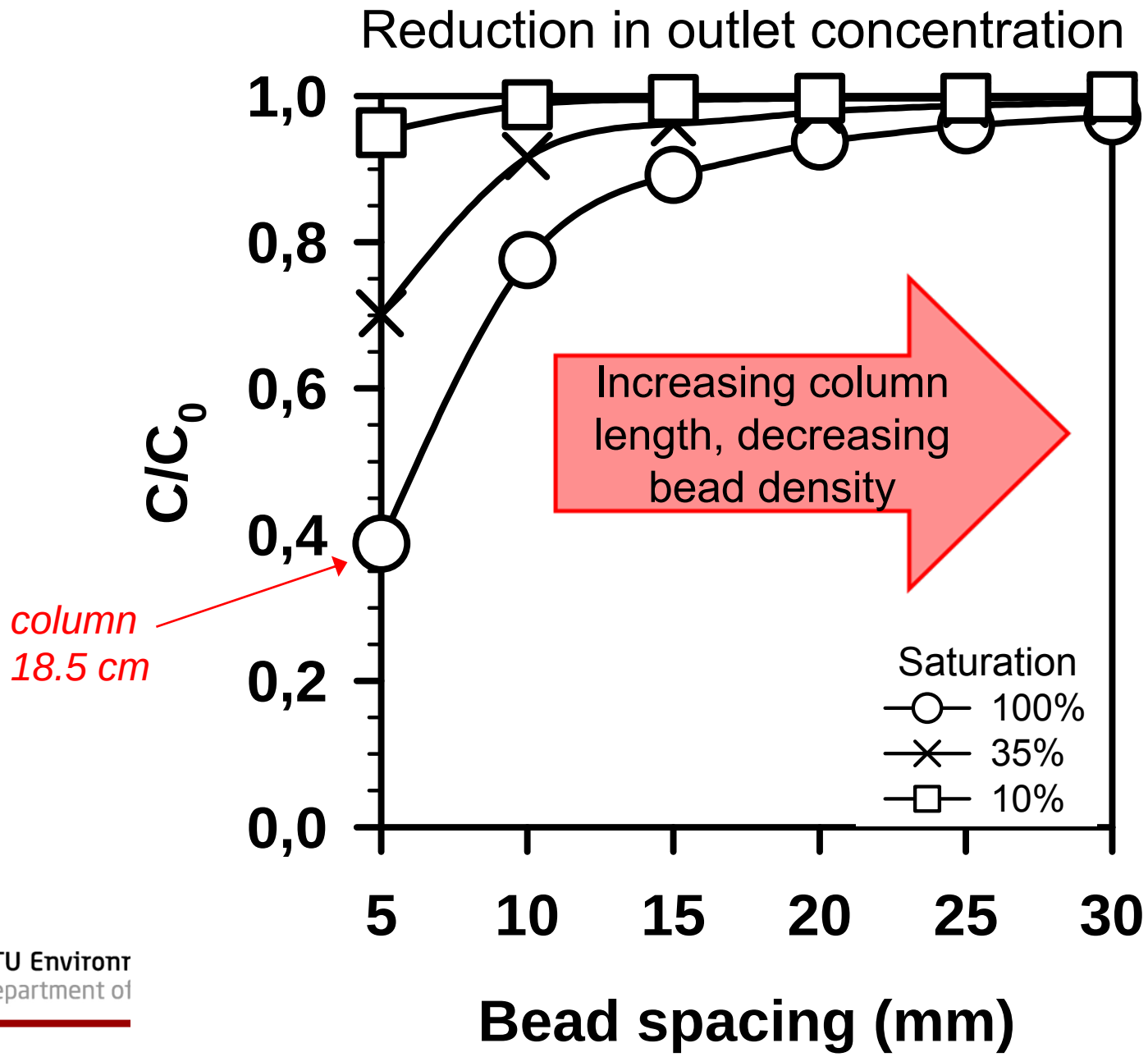
www.geograph.org.uk/photo/39325

Effect of water infiltration

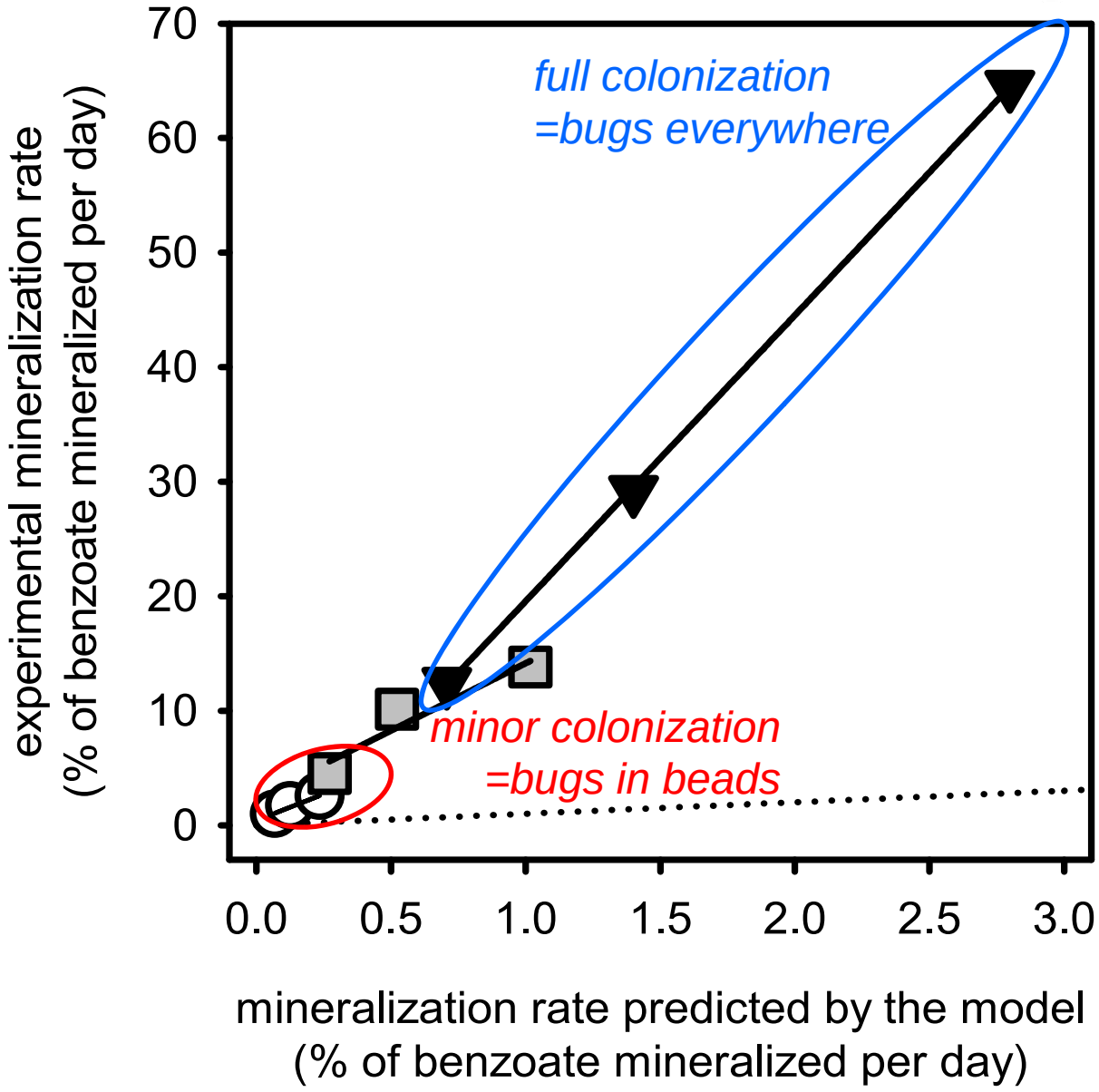
$$\frac{\partial(\theta_w + K_H\theta_a)C_w}{\partial t} - \nabla \bullet (\theta_w \mathbf{D_w} + K_H\theta_a \mathbf{D_a})\nabla C_w + q_w \frac{\partial C_w}{\partial z} + \theta_w k C_w = 0$$

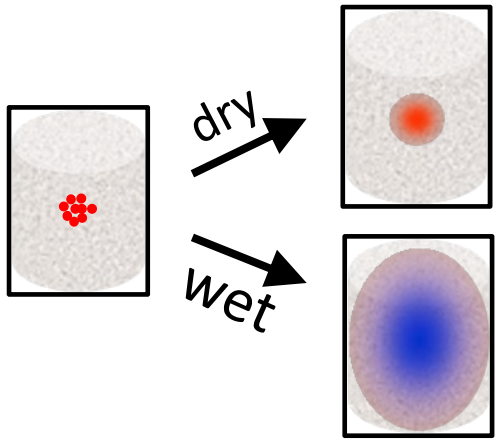


Effect of water infiltration



Effect of cell dispersal

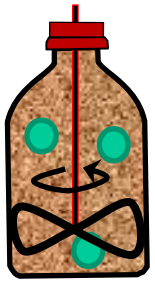




Dechesne et al. (2010) Env. Sci. Technol. 44:2386-2392

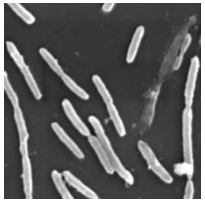
Conclusions

Bioaugmentation has poorer performance in field than expected from lab results



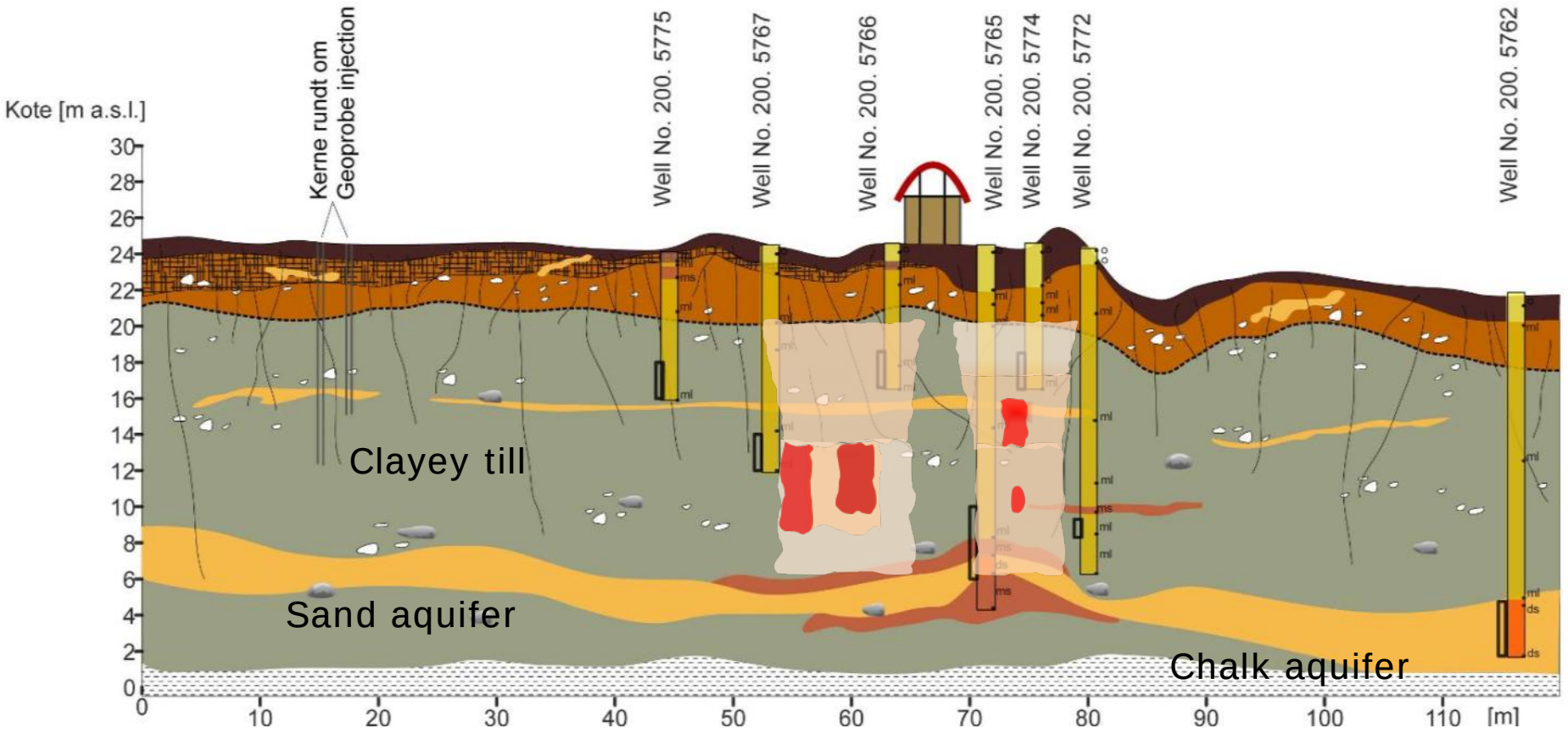
Models developed to predict field performance
- Simple Mixing Models: Can upscaling help here?
- Process models

Soil moisture, infiltration and other environmental conditions affect performance



Cell dispersal may potentially improve the technology (observed in sand, but limited in soil)

Enhanced biodegradation in clays

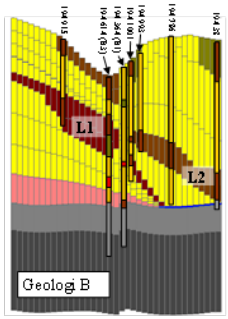


DTU og Orbicon

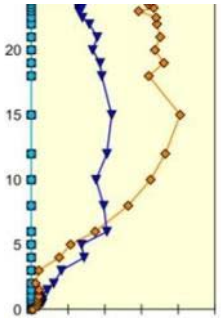
- **Long term secondary source of contamination!**
- **Remediation of chlorinated solvents?**
- **Stimulated Reductive Dechlorination, SRD?**

Geological characterization

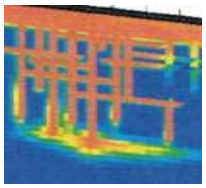
- Geostatistical tools
- Hydrogeological model



Biogeochemical site characterization



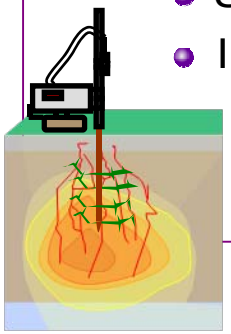
Modeling of SRD in clay till



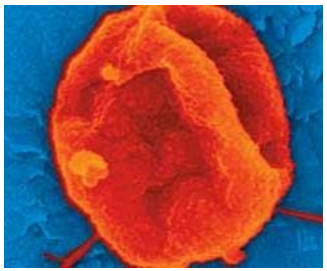
Remediation design
Practical tools

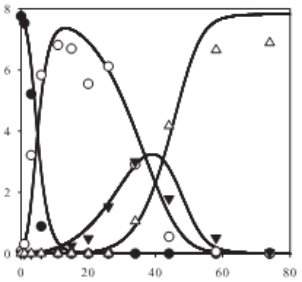
Optimization of enhancement

- Spreading of reagents
- Injection methods

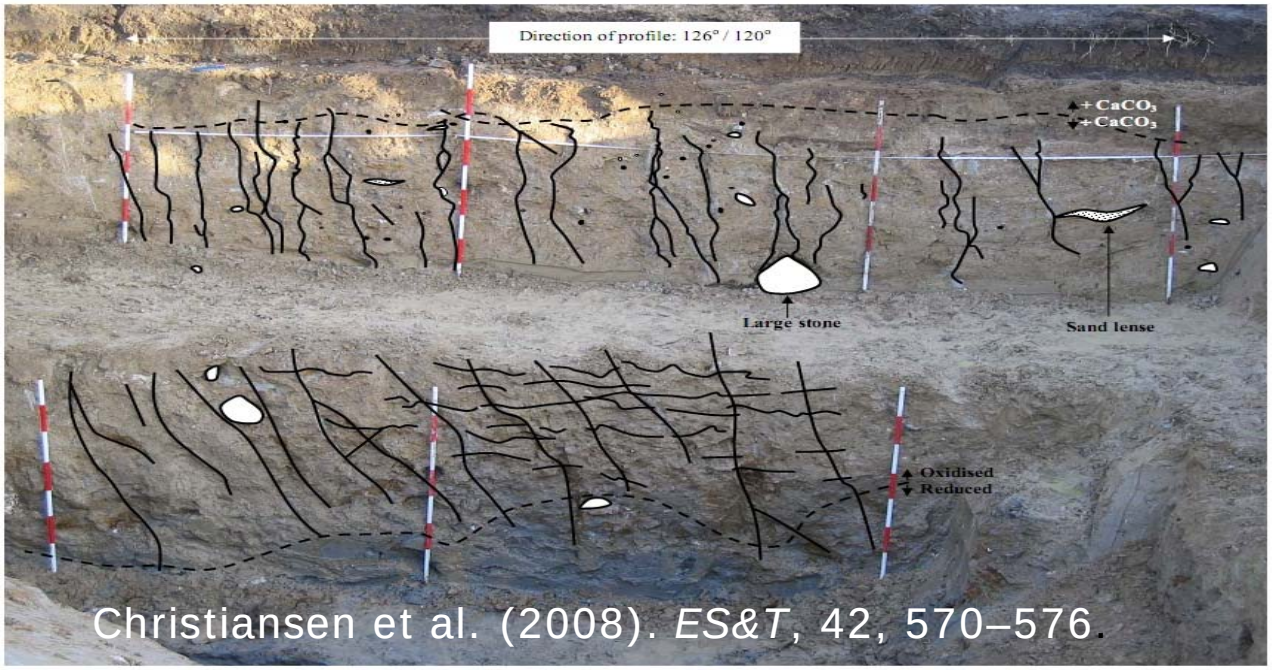


Microbial and chemical process understanding



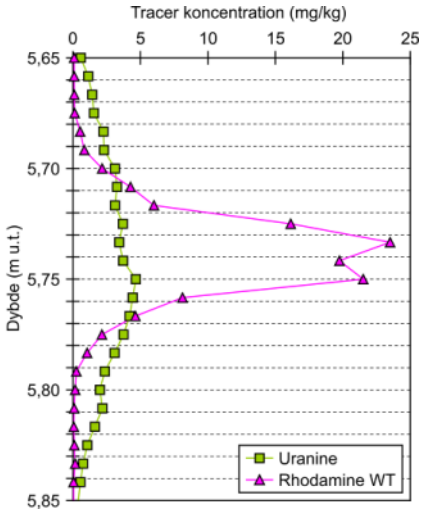


What do clays look like?



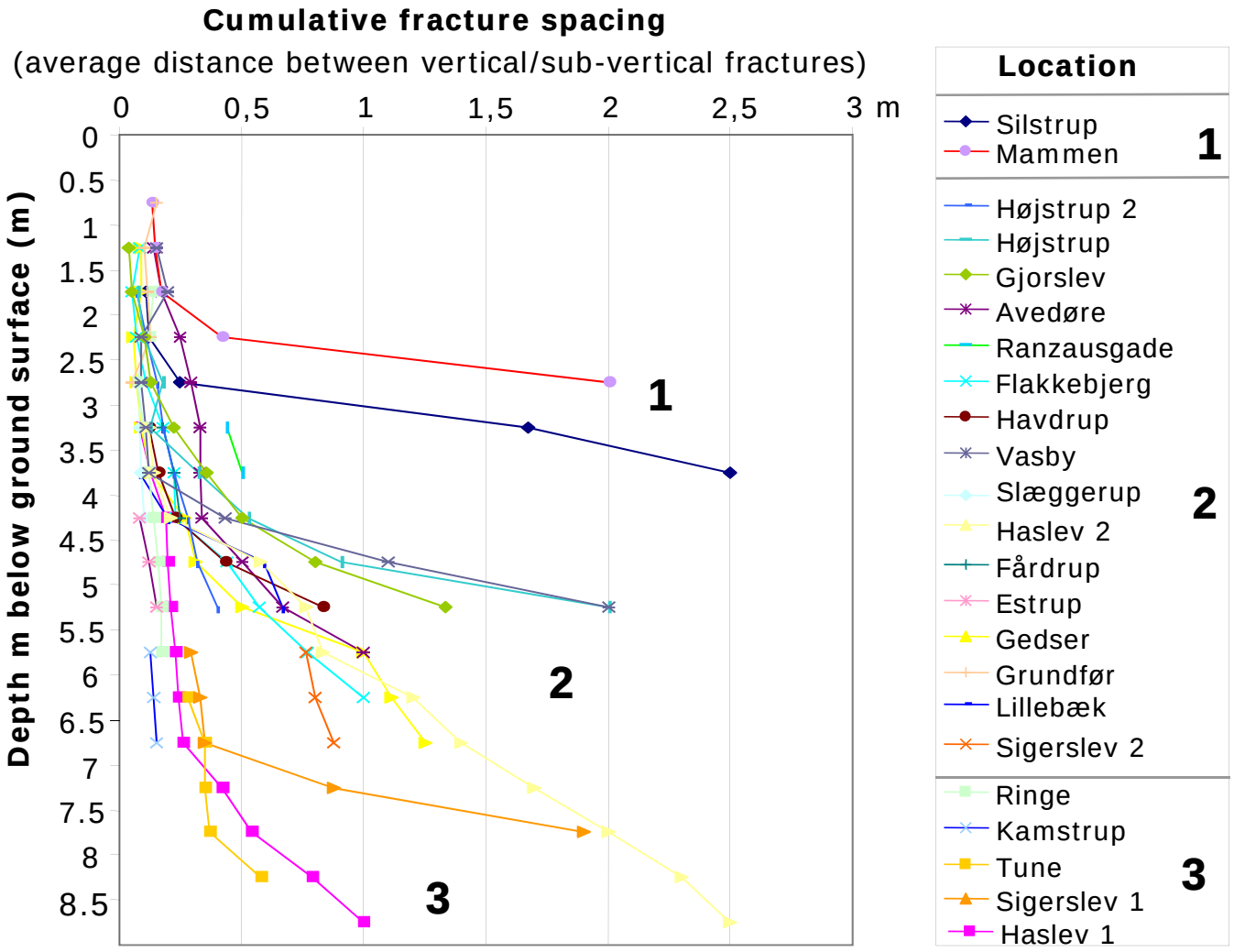
Christiansen et al. (2008). *ES&T*, 42, 570–576.

Fracture mapping



Sand lenses

Fracture distribution – Field data



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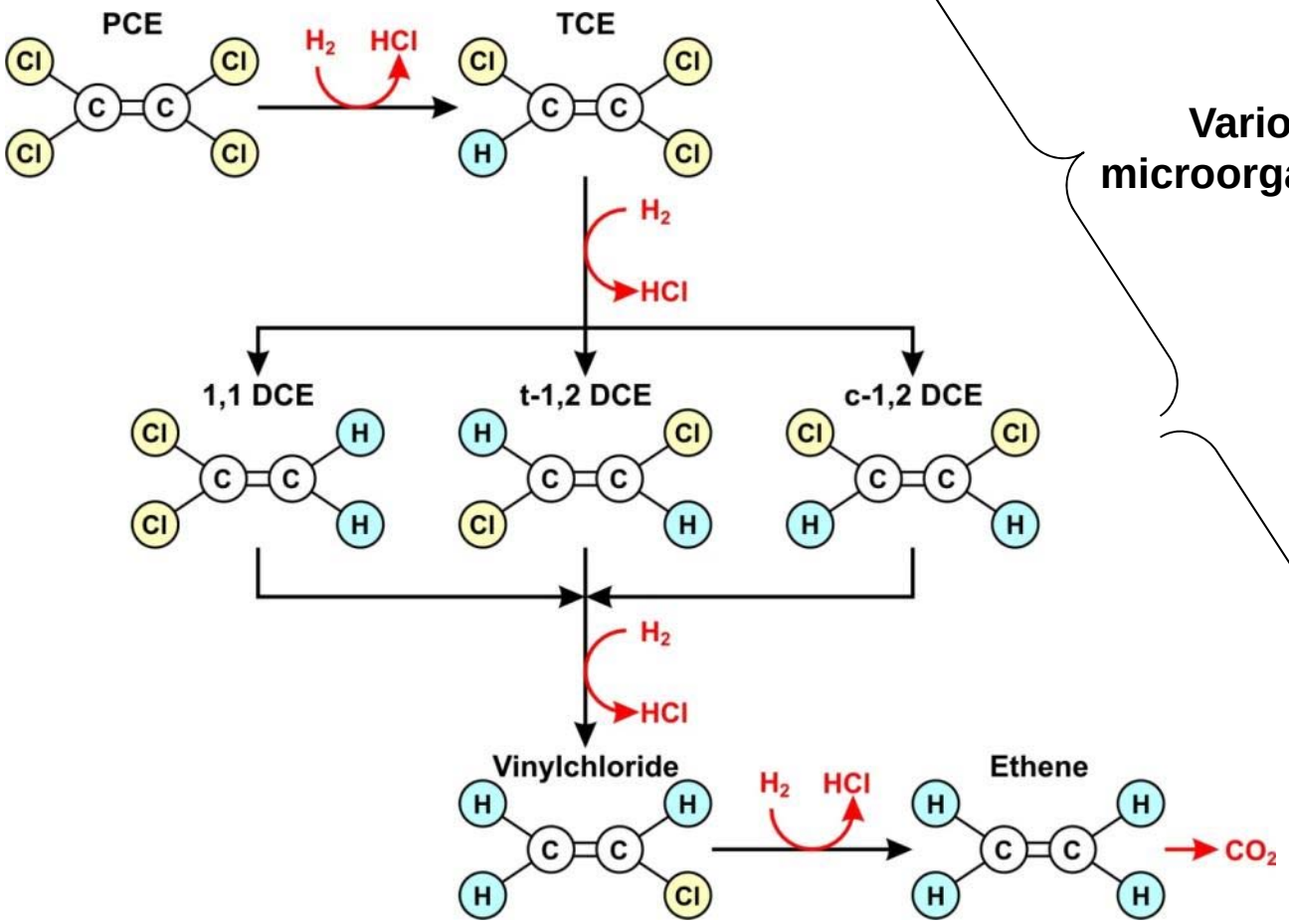
Department of Environmental Engineering

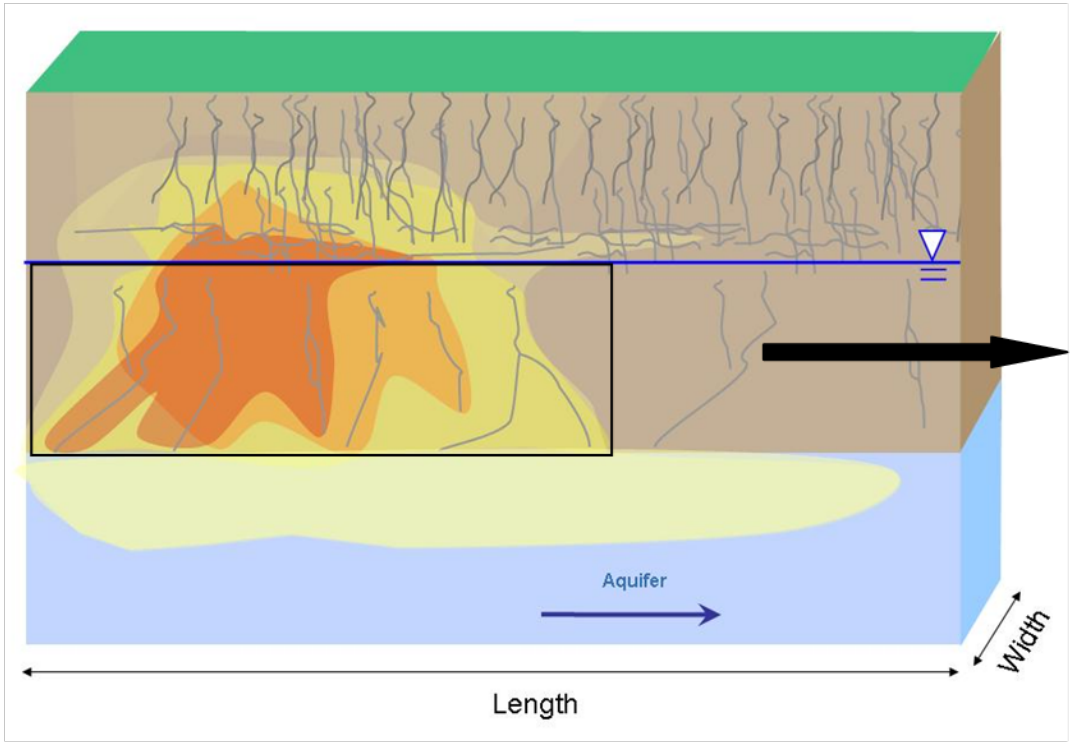
SprækkeJAGG, 2008

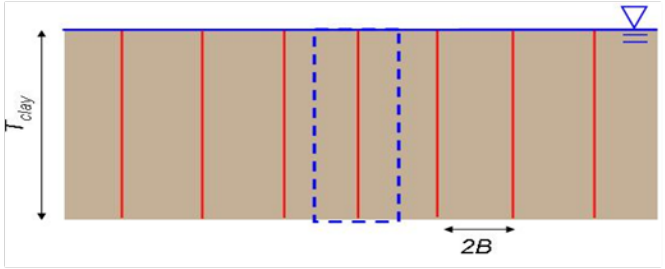
Klint, 2001, PhD Thesis

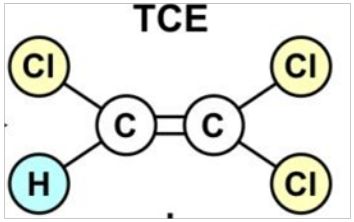
Anaerobic dechlorination



Model system - simplification

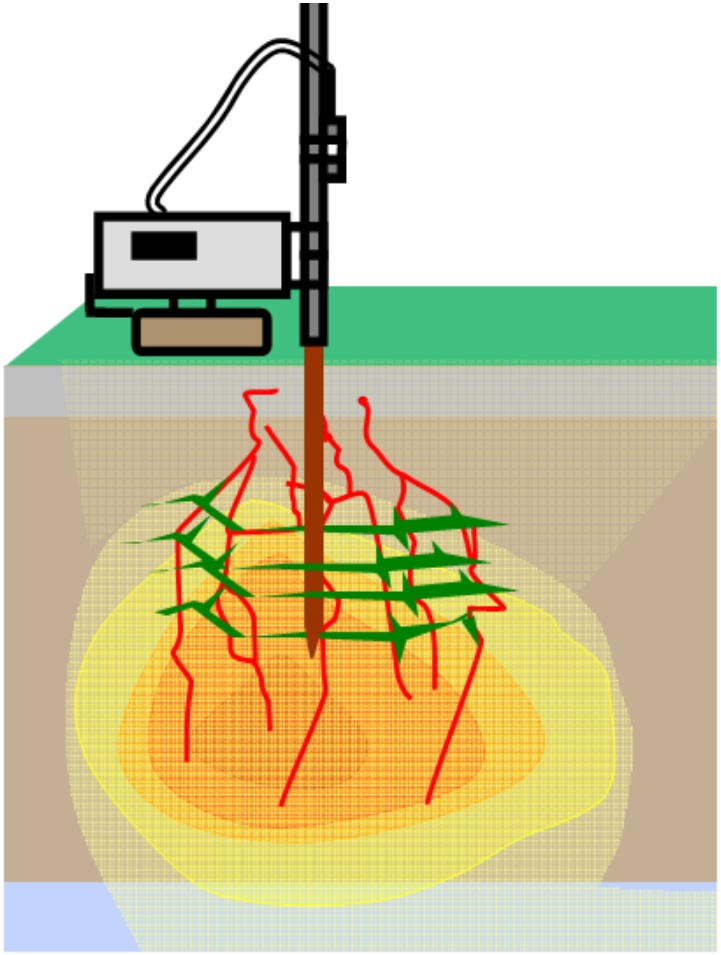


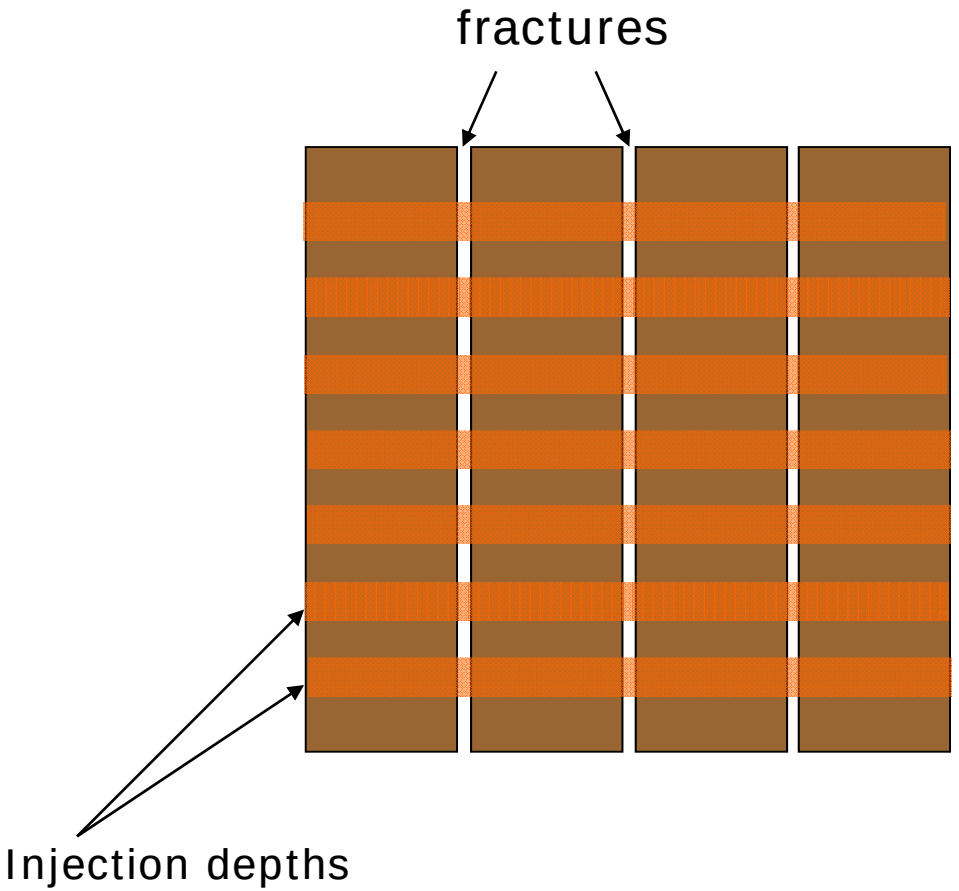




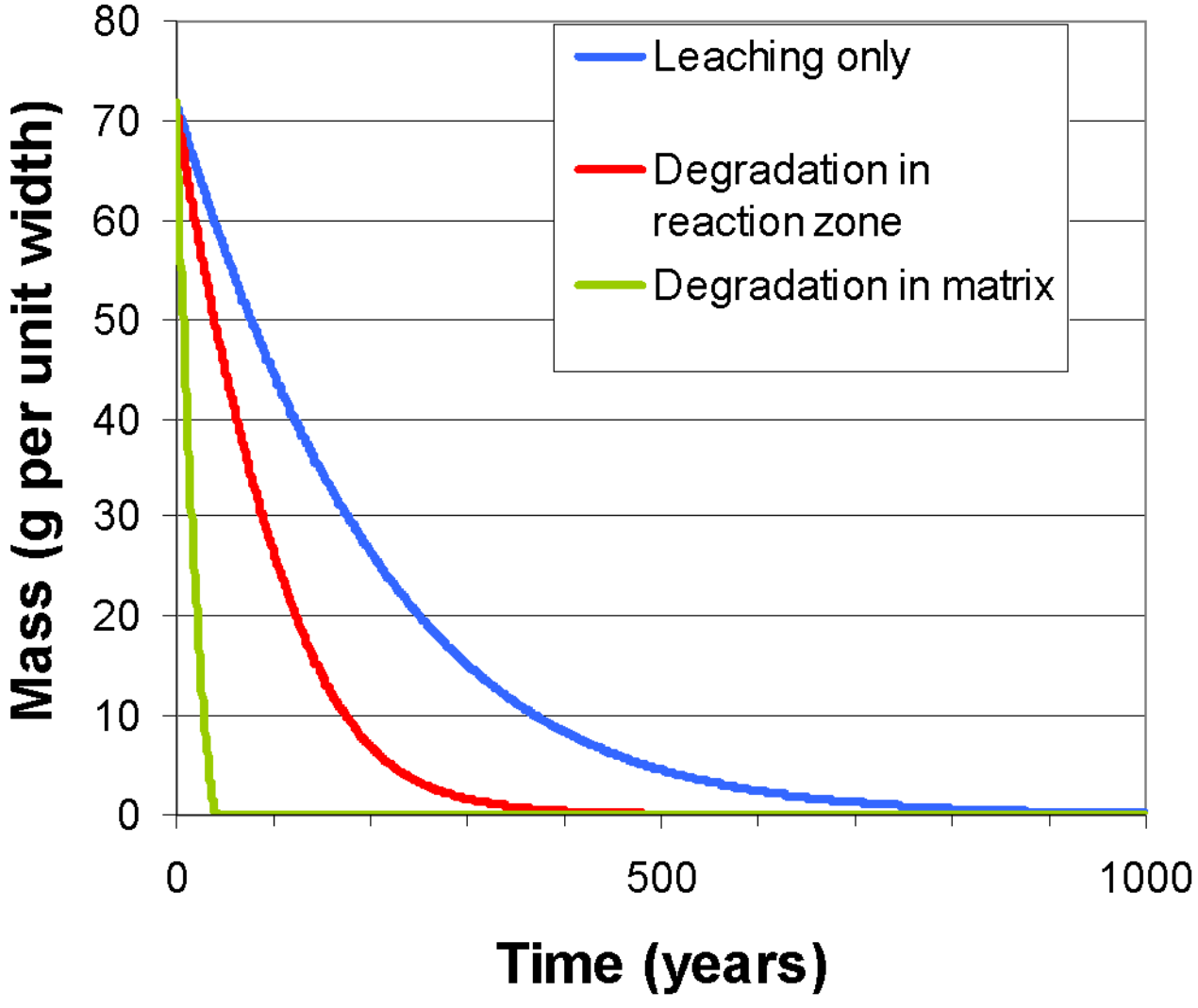
Model developed in Comsol Multiphysics

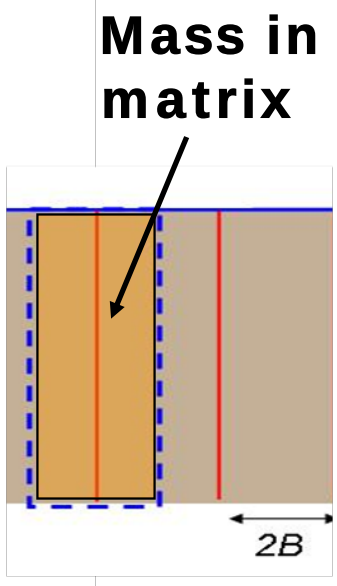
ERD injection of donor and bacteria



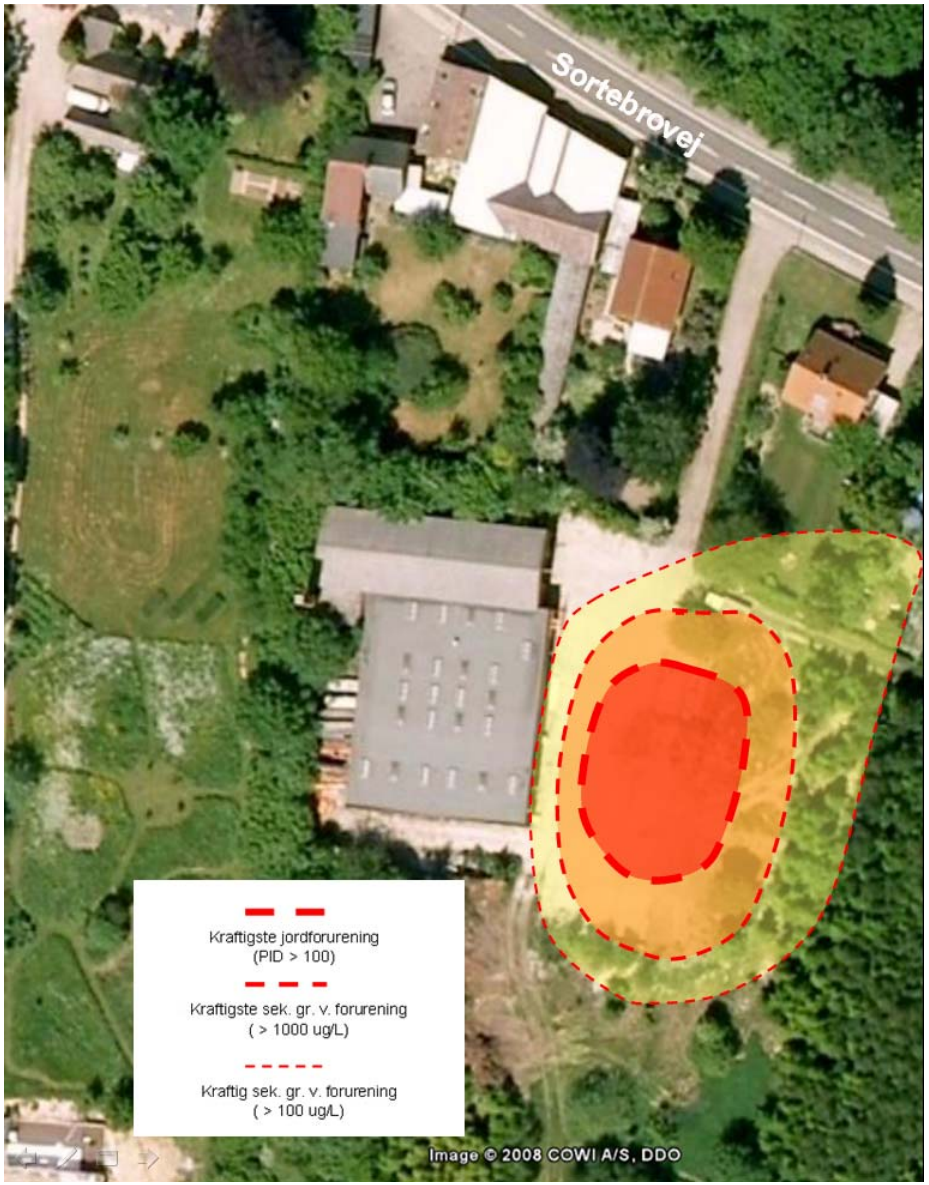


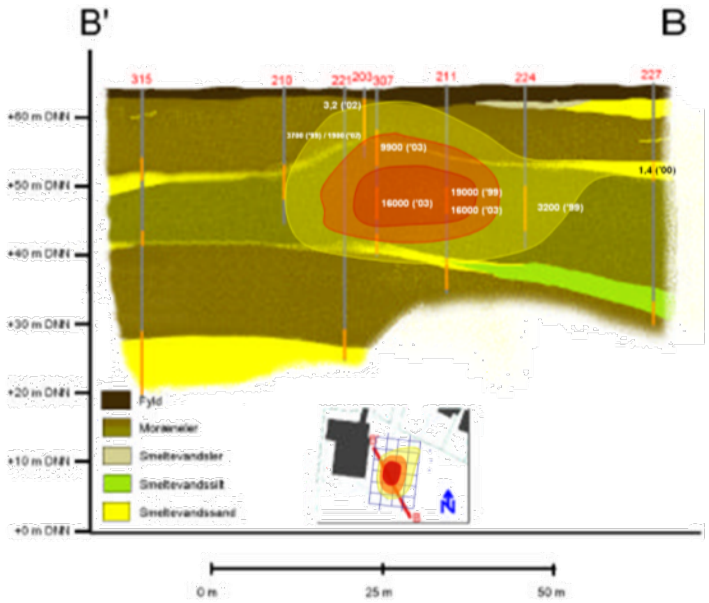
Contaminant mass in matrix
Sum of chlorinated ethenes: TCE, DCE and VC





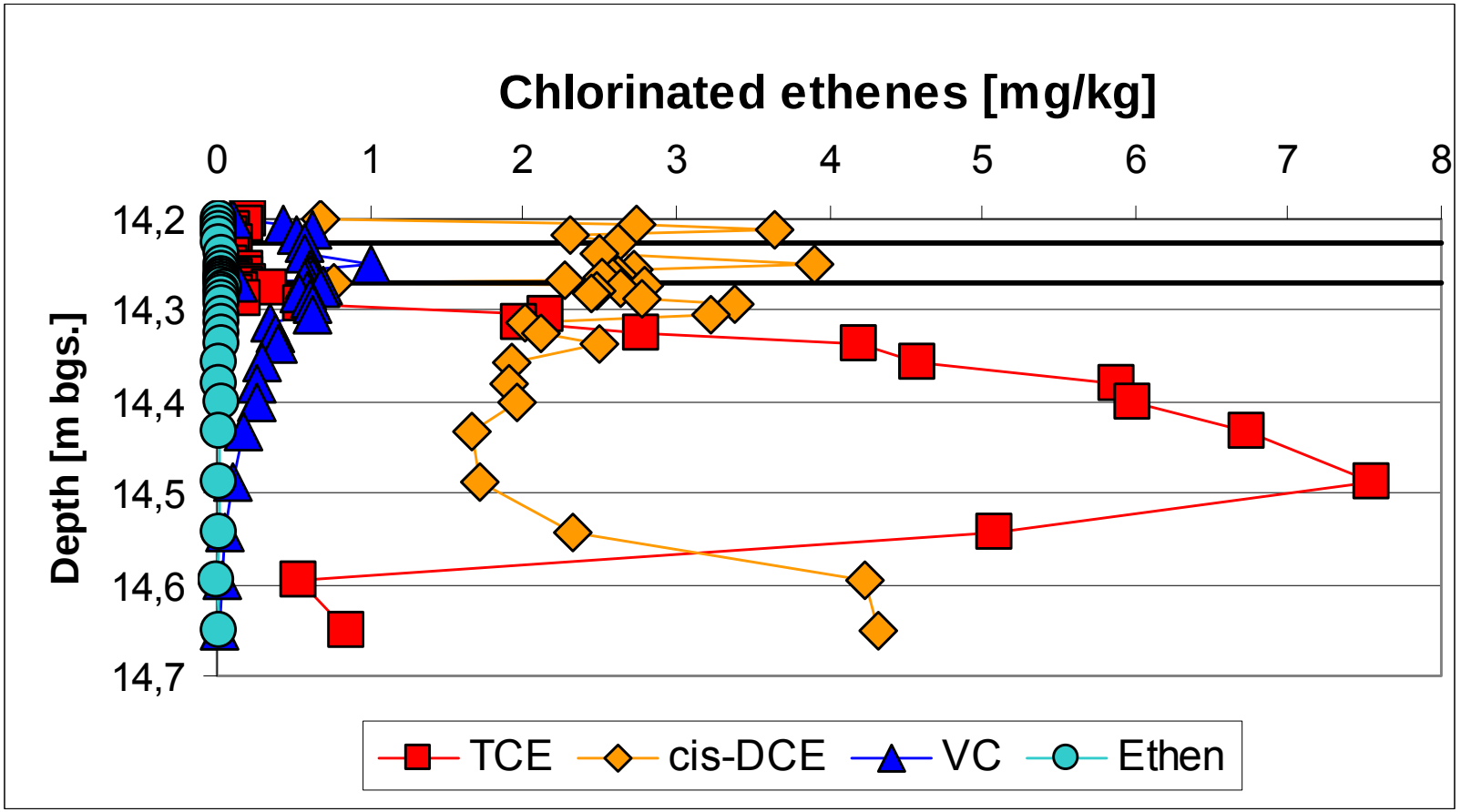
Full scale application of enhanced reductive dechlorination in clayey till (Sortebrovej, Denmark)





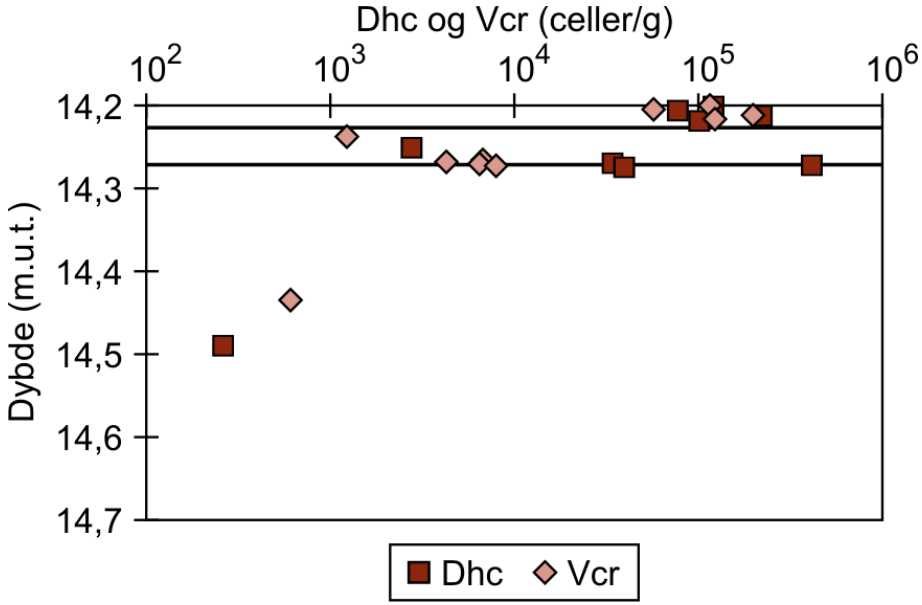
Anaerobic dechlorination associated with sandstringers in clayey till

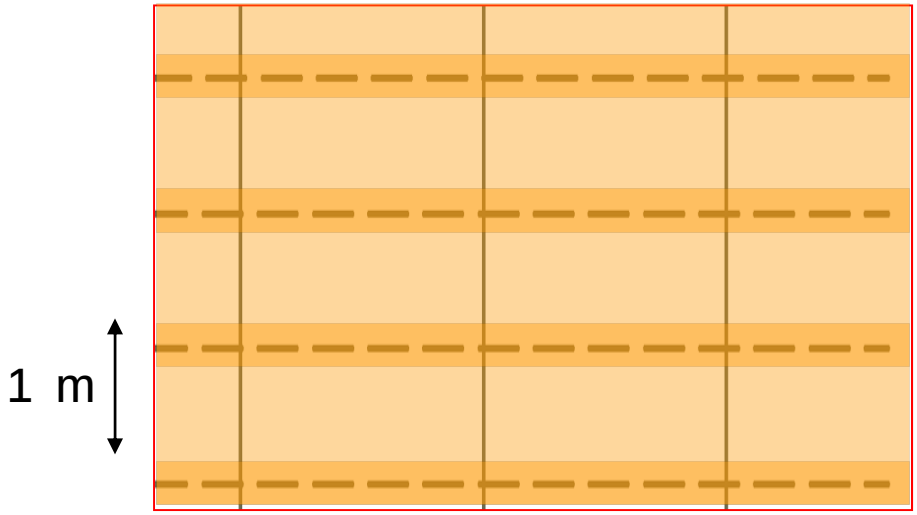
Clay core



Modeling - scenarios

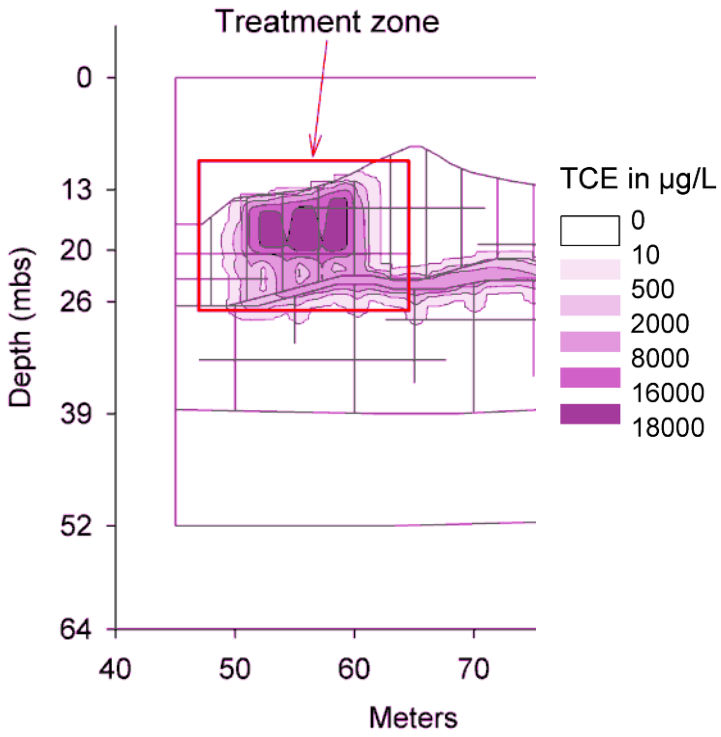
- Injection of donor in high permeability conduits
- Specific degraders only related to sandstringers or fractures
- Reaction zones surrrounding sandstringers



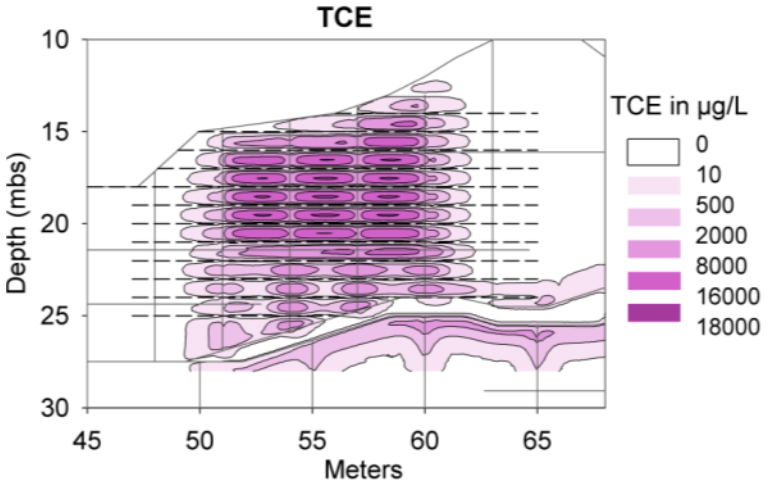


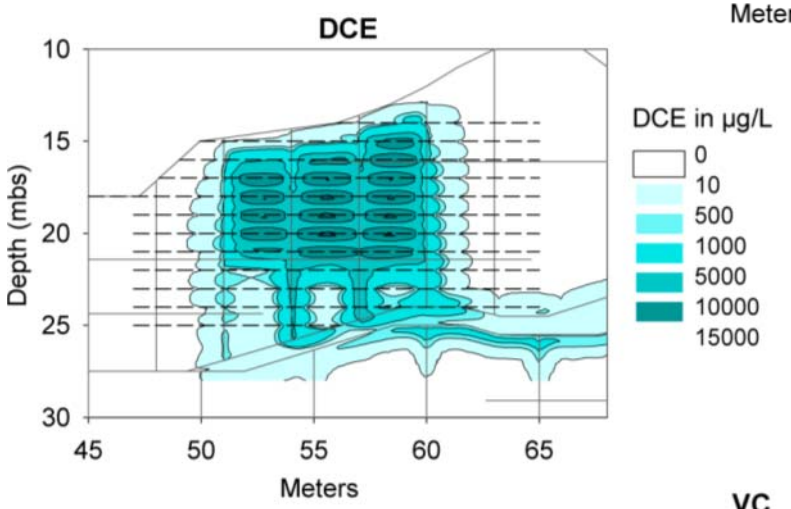
- Base line – no dechlorination
- RZ10 – 10 cm reaction zone
- RZ30 – 30 cm reaction zone
- RZ60 – 60 cm reaction zone
- Best case – entire matrix

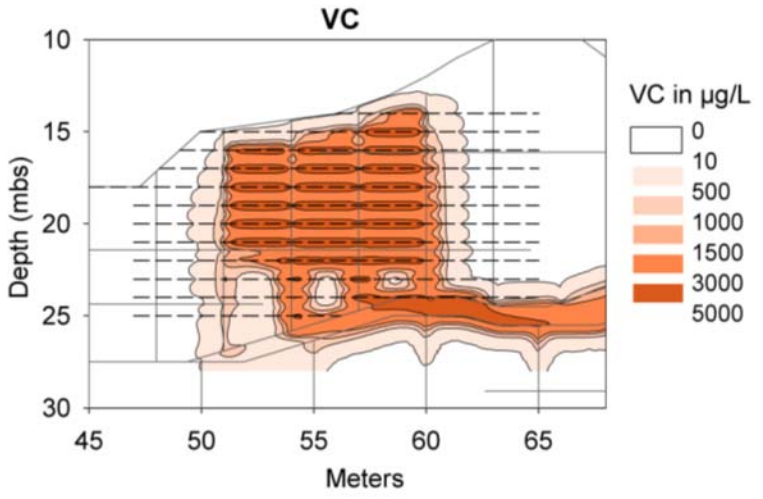
Generation of degradation products – treatment area



Before remediation



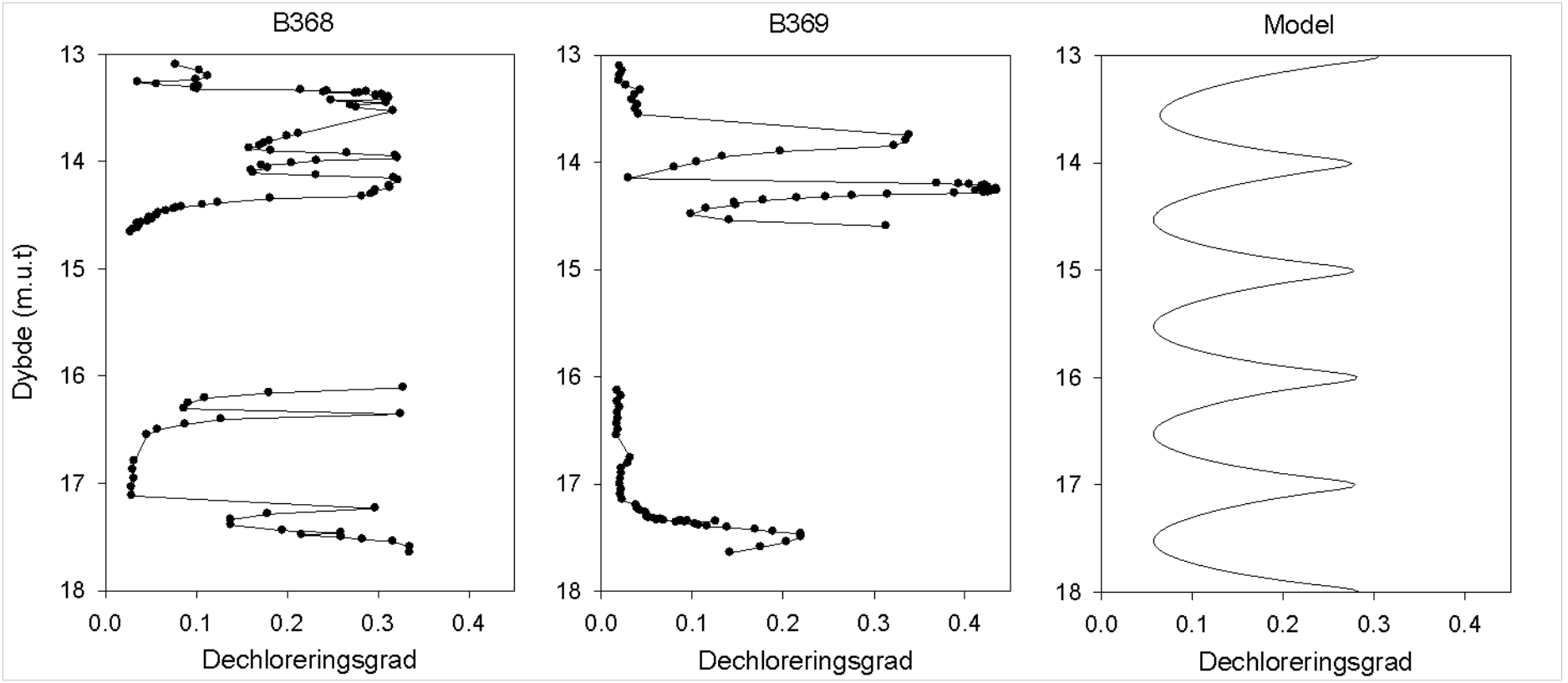




RZ30

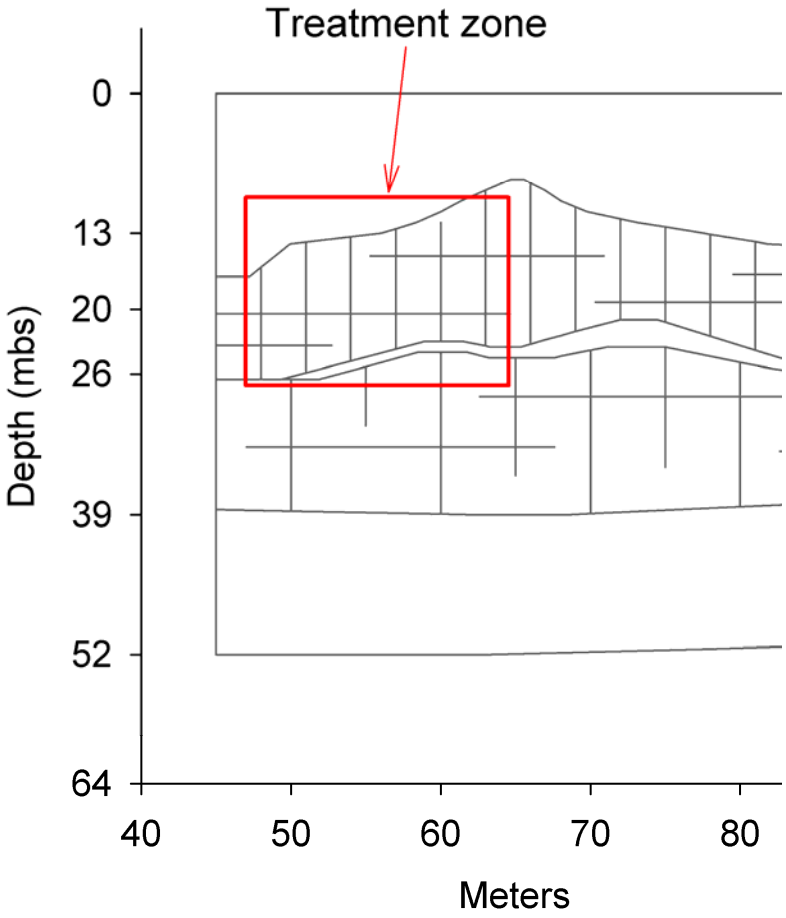
5 year after start of remediation

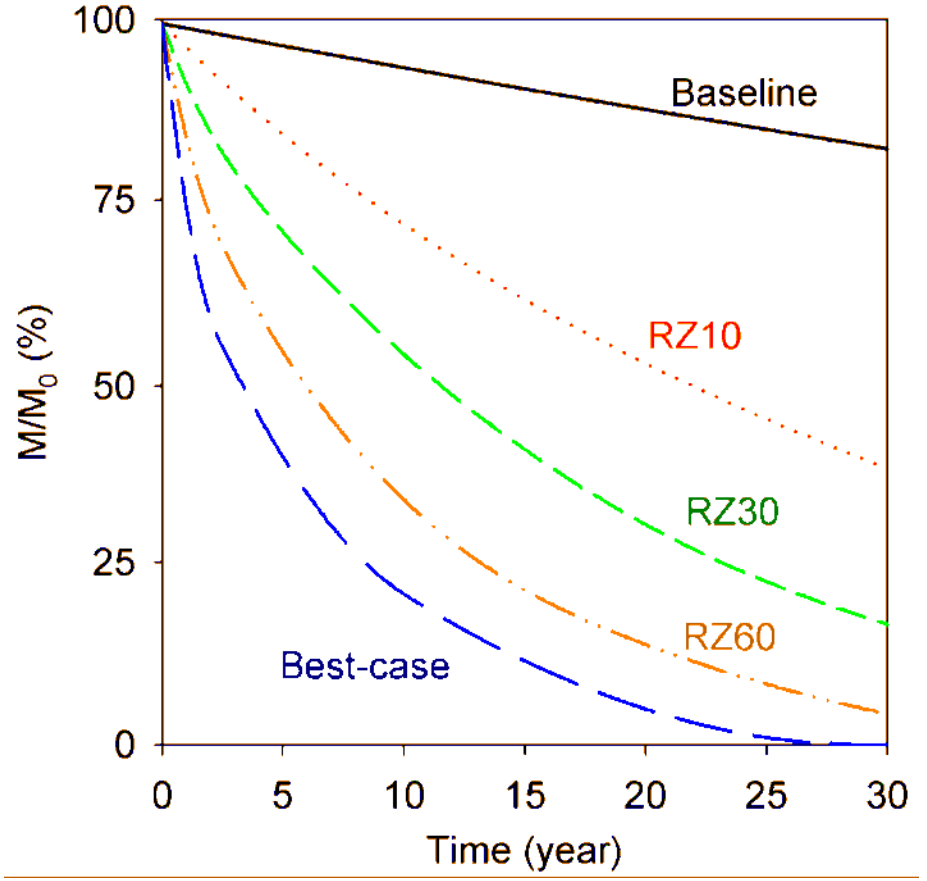
Comparison with field data



- Degree of dechlorination 2 years after remediation

Mass of contaminants in treatment area

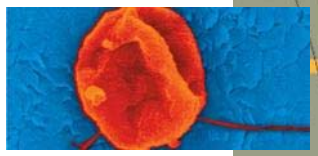


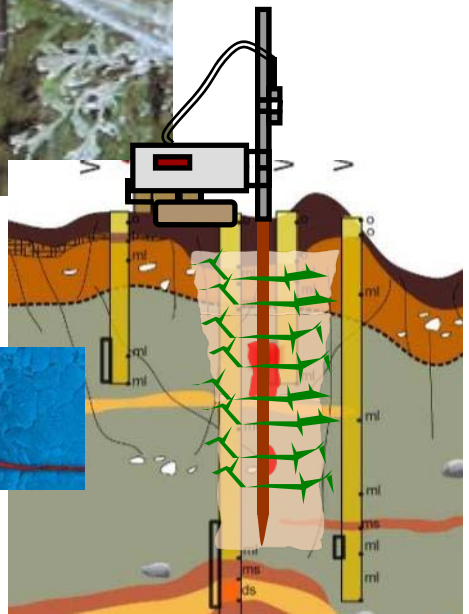


Start of remediation at day 0

Case study challenges:

- How do we model geology?
- How do we model hydraulics, including injection of substrate?
- Where are the bugs?
- How do we model the biogeochemistry?





Acknowledgements

Part 1

M. Owsianiak, A. Dechesne, B.F. Smets

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