LCA AS DECISION SUPPORT FOR REMEDIATION OF CONTAMINATED SITES: ASSESSMENT OF GROUNDWATER IMPACTS

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Introduction

- Remediation of a contaminated site aims to remove a local contamination problem but at the same time it generates environmental impacts on the local, regional and global scale. Life cycle assessment of contaminated site remediation is increasingly becoming important in decision making regarding the selection of remedial techniques

Primary impacts vs. secondary impacts:

- Secondary impacts of site remediation as a consequence of energy- and material use can be assessed with existing LCA methods
- Primary impacts can be defined as the site-specific impacts related to the contamination on the site and include as an important impact local groundwater contamination

Objectives:

- To include impacts in the groundwater compartment in the LCA of contaminated site remediation
- To establish normalization references for the groundwater impact

Groundwater impacts in LCA

- The groundwater compartment has traditionally been neglected in LCIA models
- Categories proposed to evaluate the impact on groundwater:
  - Spoiled groundwater resources
  - Human toxicity via groundwater (consistent with EDIP methodology)

Spoiled groundwater resources

- Expresses the volume of groundwater needed to dilute the emitted mass to the maximum allowable concentration (MAC) in drinking water:

$$CF\ [g/m^3] = \frac{1}{MAC}$$

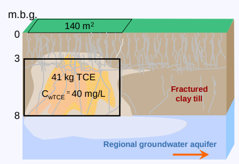
Human toxicity via groundwater

- Expresses the volume of groundwater needed to dilute the emitted mass to the human reference dose (RfD) for chronic oral exposure to groundwater (2L/day):

$$CF\ [g/m^3] = \frac{2L/day\ \ /\ 70\ kg}{RfD}$$

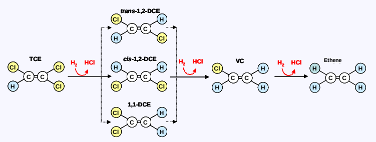
Case study and remediation scenarios

- Contaminated site in Copenhagen with 700 m^3 of contaminated soil
- App. 40 kg of chlorinated solvents (Trichloroethylene, TCE)
- Fractured clay till site overlying a regional chalk aquifer used for drinking water supply



Remediation method

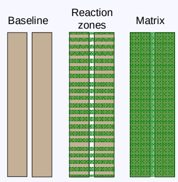
Enhanced in-situ dechlorination of TCE by injection of an organic electron donor and specific degrader organisms at various depths in the clay till:



◀ *Degradation pathway for anaerobic dechlorination of trichloroethylene (TCE) to ethene via dichloroethylene (DCE) and vinyl chloride (VC).*

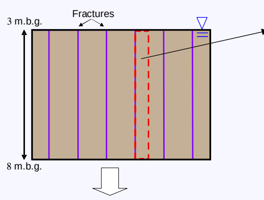
Remediation scenarios

- Baseline (no degradation, leaching only)
- Degradation in a 10 cm zone around injection depths
- Degradation in entire clay till matrix



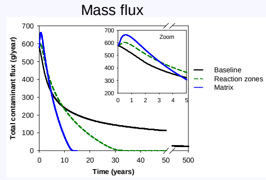
Site-specific assessment of primary impacts

- A numerical model describing the mass flux to the groundwater from the fractured clay till site undergoing enhanced in-situ dechlorination was used to evaluate:
  - The time frame for cleanup
  - The primary impact in the baseline situation and during cleanup (i.e. leached mass of TCE, DCE and VC)

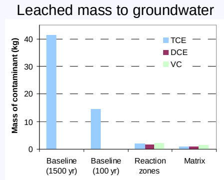


Contaminant transport:	Degradation:
➢ Diffusion in clay matrix ➢ Linear sorption ➢ Advective transport in fracture	➢ Sequential dechlorination in reactive zones: TCE → DCE → VC → Ethene ➢ Monod kinetics

Mass flux



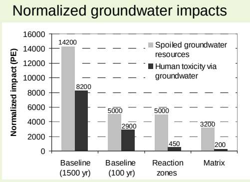
Leached mass to groundwater



◀ *The timeframe for the baseline scenario is very extended as it takes app. 1500 years before the total mass is depleted. Therefore the leached mass within a time boundary of 100 years has furthermore been evaluated.*

Normalization of groundwater impacts

Normalized groundwater impacts



▲ *The impact "spoiled groundwater resources" is based on the Danish MAC-values for TCE, DCE and VC of 1 µg/L, 1µg/L and 0.2 µg/L respectively.*

▲ *Human oral RfD-values from IRIS have been used for DCE (3.5E-2 mg/kg-day) and VC (3E-3 mg/kg-day). As TCE is currently under reassessment no value is available; the draft US EPA value of 3E-4 mg/kg-day has been used.*

Applied normalization references:

- Spoiled groundwater resources:

  2900 m^3/person/year (Denmark)

  Based on the annual discharge of nitrate from agriculture and the annual discharge of chloride from waste disposal sites.
- Human toxicity via groundwater:

  480 m^3/person/year (Denmark)

  Based on the annual discharge of nitrate and pesticides to groundwater.

Preliminary conclusions and outlook

- ➢ The results indicate that primary impacts in the groundwater compartment are of significant magnitude in terms of person equivalents (PE) for enhanced in-situ bioremediation of TCE. In contrast, the secondary impacts (data not shown) are minor. The secondary impacts of alternative more energy intensive techniques (in situ thermal desorption) are in the order of 100 PE
- ➢ The primary impacts of the baseline scenario without remediation depend on the chosen time boundary of the impact assessment
- ➢ The remediation does not reduce the "spoiled groundwater resources" significantly in a 100 year timeframe due to formation of vinyl chloride
- ➢ The "human toxicity via groundwater" is significantly reduced by remediation. However the applied human RfD value for TCE is a draft value making the evaluation of this impact uncertain
- ➢ Normalization references for impacts in the groundwater compartment are preliminary and need to be further developed