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I{ Relationship between source clean up and mass flux of chlorinated solvents in low permeability settings with fractures}

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Groundwater contamination by chlorinated solvents, such as perchloroethylene (PCE), often occurs via leaching from complex sources located in low permeability sediments such as clayey tills overlying aquifers. Clayey tills are mostly fractured, and contamination migrating through the fractures spreads to the low permeability matrix by diffusion. This results in a long term source of contamination due to back-diffusion. Leaching from such sources is further complicated by microbial degradation under anaerobic conditions to sequentially form the daughter products trichloroethylene, cis-dichloroethylene (cis-DCE), vinyl chloride (VC) and ethene. This process can be enhanced by addition of electron donors and/or bioaugmentation and is termed Enhanced Reductive Dechlorination (ERD).

This work aims to improve our understanding of the physical, chemical and microbial processes governing source behaviour under natural and enhanced conditions. That understanding is applied to risk assessment, and to determine the relationship and time frames of source clean up and plume response. To meet that aim, field and laboratory observations are coupled to state of the art models incorporating new insights of contaminant behaviour.

The long term leaching of chlorinated ethenes from clay aquitards is currently being monitored at a number of Danish sites. The observed data is simulated using a coupled fracture flow and clay matrix diffusion model. Sequential degradation is represented by modified Monod kinetics accounting for competitive inhibition between the chlorinated ethenes. The model is constructed using Comsol Multiphysics, a generic finite- element partial differential equation solver. The model is applied at well characterised field sites with respect to hydrogeology, fracture network, contaminant distribution and microbial processes (lab and field experiments). At one of the study sites (Sortebrovej), the source areas are situated in a clayey till with fractures and interbedded sand lenses. The site is highly contaminated with chlorinated ethenes which impact the underlying sand aquifer. Full scale remediation using ERD was implemented at Sortebrovej in 2006. Anaerobic dechlorination is taking place, and cis-DCE and VC have been found in significant amounts in monitoring wells and to some degree in sediment cores representing the the clayey till matrix.

Model results reveal several interesting findings. The physical processes of matrix diffusion and advection in the fractures seem to be more important than the microbial degradation processes for estimation of the time frames and the distance between fractures is amongst the most sensitive model parameters. However, the inclusion of sequential degradation is crucial to determining the composition of contamination leaching into the underlying aquifer. Degradation products like VC will peak at an earlier stage compared to the mother compound due to a higher mobility. These model results are supported by actual findings at the Sortebrovej site.

The findings highlight a need for improved characterization of low permeability aquitards lying above aquifers used for water supply. The fracture network in aquitards is currently poorly described at larger depths (below 5-8 m) and the effect of sand lenses on leaching behaviour is not well understood. The microbial processes are assumed to be taking place in the fracture system, but the interaction with and processes in the matrix need to be further explored. Development of new methods for field site characterisation and integrated field and model expertise are crucial for the design of remedial actions and for risk assessment of contaminated sites in low permeability settings.