Determination of the contaminant mass discharge from low-conductive layers based on scenario modeling and high-resolution concentration profiles

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Many source zones of contaminated sites are located in low-conductive layers, such as glacial sediments, which are common on the Northern Hemisphere. In these layers, the contaminant can be sorbed to the matrix and additionally fractures can lead to the diffusion of the contaminant into the matrix, where it is stored and released over a long time span. From the low-conductive layer, the contaminant can leach vertically and pose a long-term threat to an underlying groundwater aquifer. Quantifying the contaminant mass discharge to assess the risk that the contaminated site poses to the groundwater and water supply wells can be challenging and requires usually extensive site investigations.

We present a methodology to estimate the approximate contaminant mass and the contaminant mass discharge from a chlorinated solvent source zone in a low-conductive layer to an underlying aquifer. The approach applies an innovative combination of relatively easily accessible field measurements and solute transport modeling. This can be used as a screening tool to evaluate, if a contaminated site poses a threat to groundwater resources and to assess the need for remedial actions.

To develop and test the approach, we have investigated a contaminated field site in eastern Denmark, where a TCE spill from an industrial production site has caused a dissolved chlorinated solvent plume. TCE first leached through a low-conductive clayey-till layer potentially containing small-aperture fractures, into the underlying sandy aquifer, where groundwater flow led to a mostly horizontal spreading. The site had been investigated with an extensive set of measurements, including soil samples and sorption tests in order to determine the mass distribution, slug tests, and measurements of chlorinated ethenes in groundwater.

We determined high-resolution depth-discrete hydraulic profiles and concentration profiles at several measurement locations in the aquifer. A detailed 3-D flow and transport model (with ca. 12 million mesh elements) was then calibrated to the field data and used to interpret the extensive set of measurements. The contaminant mass in the source zone and the transport from the clayey till to the sandy aquifer could be efficiently quantified based on the hydrogeological input data and the model calibration to the shapes of the vertical concentration profiles.

Simplifying the 3-D setup, a generic 2-D model was developed and the results from the 2-D model were compared to the ones from the detailed 3-D model. To explore the potential influence of fractures on the source zone depletion and plume evolution, a discrete-fracture submodel was employed in the low-conductive layer and contaminant input functions to the aquifer were developed and tested. A local sensitivity analysis was used to determine key influential parameters and measurements and to address uncertainties of the presented approach.

The generic 2-D model was used to estimate the contaminant mass discharge by comparing the detailed vertical concentration profiles with the simulated profiles from scenario modeling. The results compare very well with traditional but much more expensive methods to determine the contaminant mass discharge in the underlying aquifer. The modeling accounts for the interplay between vertical water and contaminant fluxes through the low-conductive, potentially fractured layer and the horizontal groundwater flow. The concept is now being built into a tool, which is going to be applied for risk assessment at contaminated clayey-till sites by Danish authorities.

References

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