282c Solute Fate in Stratified Heterogeneous Media

Julio A. Zimbron, Tom C. Sale, and David S. Dandy

Standard industrial practices of past decades have resulted in inadvertent releases of chlorinated solvents to the environment. Commonly this has been associated with storage and/or disposal practices at industrial facilities. Fortunately, recognition of the resultant problems has led to dramatically improved storage/use/disposal practices and greatly reduced the frequencies of releases. A primary outcome of improved practices is that most dense non-aqueous phase liquid (DNAPL) releases are old--10, 20 or even 50 years. Field studies show that the age of a release can have a strong bearing on distribution of contaminants in a source zone and efficacy of source control technologies. Given a large enough release, DNAPL will migrate downward to the groundwater zone. In the groundwater zone DNAPL displaces water and occurs (typically) as a non-wetting phase within the porous or fractured medium. Although DNAPL is only sparingly soluble in water, the contact between these two phases will cause the water adjacent to the source to become saturated. Dissolution of DNAPL constituents into the water phase depletes the remaining DNAPL. Transport processes, such as advection, dispersion, and diffusion, carry dissolved constituents away from the source and drive further DNAPL dissolution. In addition, dissolved DNAPL constituents in water can adsorb onto the solids that make up the porous media. Sorption acts as a sink that accelerates rates of DNAPL dissolution.

Most conceptualizations of mass transfer presented to date are limited by the assumption of a uniform porous medium. In actuality, porous media, even materials that visually appear to be uniform, are typically very heterogeneous. Groundwater flow velocities can easily vary by orders of magnitude within different layers of natural sediments, e.g., sand and silt. Also, the capacity of different sediments to store sorbed contaminant mass can vary by orders of magnitude. All of this heterogeneity has great relevance to the mechanisms by which contaminants are stored and released from source zone to downgradient plumes. In this combined experimental and theoretical study, the impact of heterogeneity on solute transport was determined using a simple two-layer system. The value of this simple case is that it allows rigorous analysis of governing processes via laboratory experiments and analytical models developed from first principles. The system studied consists of a 1 m horizontal "semi-infinite" sand layer overlying a semi-infinite silt layer. The contrast in permeability between the two layers is large enough that the sand layer is viewed as hydraulically transmissive and the silt is viewed as hydraulically stagnant. This presents an important conceptualization of porous media as bodies containing intervals of flowing and stagnant groundwater. In different tanks, point sources of PCE, TCE, and MTBE are applied as solutes to mimic mass flux from a DNAPL source, and are active for a period of 25 days. Subsequently, the sources are shut off and water only is flushed through the tanks for an additional 58 days. Through the duration of the experiments contaminant discharge is resolved as a function of time. Results indicate that even for this short length, the silt layers retain between 15 to 44 percent of the introduced contaminants at the end of the experiment. Upon removal of the contaminant sources, back diffusion sustains contaminant concentrations in the tank effluent at levels two to four orders of magnitude above typical maximum contaminant levels (MCLs). Considering the mass retained in the silt layers, it appears that extremely long period of time would be required to flush sufficient water through the tank to achieve MCLs. Analytical solution of the species conservation equations in the sand and silt layers demonstrates that, with no adjustable parameters, the experimental results can be readily duplicated. Further, by including the effects of solute adsorption and homogeneous degradation in the equations, it is possible to probe different scenarios for solute fate and potential treatment strategies.