Geophysical Research Abstracts
Vol. 20, EGU2018-1282-1, 2018
EGU General Assembly 2018

Multiscale Transport of LNAPL in Subsurface Under Varying Subsurface Flow Conditions

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Variation in groundwater flow is expected in aquifers subjected to dynamic environmental conditions and changes in groundwater extraction patterns. Subsurface pollution due to release of light non-aqueous phase liquids (LNAPL) is of major concern under varying groundwater flow conditions because of their higher water solubility and wide coverage in subsurface as copmared to dense NAPL. Hence, the aim of this study was to investigate the impact of groundwater flow extremes on fate and transport of toluene, the selected LNAPL, in subsurface using a series of practical and numerical modeling. An air tight three-dimensional tank setup of size 60cm-L×30cm-W×60cm-D embedded with horizontal and vertical layers of sampling ports was fabricated for this purpose. Organic content free clean sand with grain size of ranges 0.5-1.0 mm was packed in the tank to create a subsurface system consisting of an unsaturated zone underlain by a shallow phreatic aquifer system. Pure phase of the selected LNAPL was released from top surface of the tank setup to create a pool of the LNAPL above the groundwater table which was maintained at 35 cm from the tank bottom. For investing role of groundwater flow on toluene's fate and transport, a constant water flux was allowed to flow first for maintaining a flow velocity of 1.2 m/day in the horizontal direction to mimic a general groundwater flow regime. The flow velocity was then increased/decreased by changing the water flux passing through the saturated zone by keeping the water table location at the same height. Pore water and soil vapor samples were collected routinely from the sampling ports and were analyzed using GC-MS/IRMS. A numerical domain representing LNAPL polluted site was developed to simulate the coupled processes involved multiphase flow, and to quantify the impact of groundwater on LNAPL behaviors. The LNAPL mass transfer coefficient was found to increase with velocity and was estimated for the selected groundwater flow regimes varying from 0.083 to 0.129 cm/h. Linear correlations were observed between groundwater water velocity and 1) mass transfer coefficient, 2) Sherwood, and 3) Peclet number. The observed high rate of degradation of the toluene for faster flow velocities fortifies the dependency of the degradation kinetics on dissolved LNAPL concentration. The observed breakthrough curves (BTCs) at different ports showed that horizontal and transverse transport of the LNAPL was more prominent as compared to its vertical movement. The observed concentration isolines curve shows larger area coverage by the LNAPL plume under the faster groundwater flow conditions due to high mechanical dispersion and shear force acting on interface between pure toluene and groundwater. The observed concentration of dissolved toluene compared well with the simulated curves for the three cases of groundwater flow conditions. The results of this study are of direct use in applying bioremediation techniques in field having dynamic groundwater conditions.