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A Bayesian Approach to Integrate Real-Time Data into Probabilistic Risk Analysis of Remediation: A Field Application

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The release of non-aqueous phase liquids (NAPLs) such as petroleum hydrocarbons and chlorinated solvents in the subsurface is a severe source of groundwater and vapor contamination. Because these liquids are essentially immiscible due to low solubility, these contaminants get slowly dissolved in groundwater and/or volatilized in the vadoze zone threatening the environment and public health over a long period. Many remediation technologies and strategies have been developed in the last decades for restoring the water quality properties of these contaminated sites. The failure of an on-site treatment technology application is often due to the unnoticed presence of dissolved NAPL entrapped in low permeability areas (heterogeneity) and/or the remaining of substantial amounts of pure phase after remediation efforts. Full understanding of the impact of remediation efforts is complicated by a complex interplay of physical and biochemical processes taking place through several potential pathways of exposure to multiple receptors in a highly unknown heterogeneous environment. Due to these difficulties, the design of remediation strategies and definition of remediation endpoints have been traditionally determined without quantifying risks associated with the failure of such efforts. We conduct a probabilistic risk analysis (PRA) of the likelihood of success of an on-site NAPL treatment technology that easily integrates all aspects of the problem (causes, pathways, and receptors) without doing extensive modeling. Importantly, the method is further capable of incorporating the inherent uncertainty that often exist in the exact location where the dissolved NAPL plume leaves the source zone. This is achieved by describing the system failure as a function of this source zone exit location, parameterized in terms of a vector of parameters. Using a Bayesian interpretation of the system by means of the posterior multivariate distribution of the vector of parameters, the failure of the treatment technology is then updated given the observed real-time measurements of concentrations at nearby monitoring wells. Thus, the methodology allows one to combine the probability of failure of a remediation effort due to multiple causes; each one associated with different potential pathways and receptors, and to integrate real-time measurements into a PRA analysis. A field application of the method is presented with the aim to identify the location of the source zone in a probabilistic framework.