Integration of hydraulic, hydrochemical and isotope data to evaluate the fate of chlorinated ethenes at the groundwater-surface water interface

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Chlorinated ethenes are among the most frequently detected contaminants in groundwater in developed countries, and they can be degraded by various redox-dependent reactions. Sequential reductive dechlorination is frequently observed under anaerobic conditions, but the complete degradation to ethene requires strongly reducing conditions. Some chlorinated ethenes can also be oxidized metabolically and cometabolically under aerobic or anaerobic conditions. Since the groundwater-surface water interface is expected to develop a series of complex redox conditions, it may serve as an important zone for reducing the contaminant mass. A detailed field investigation was carried out to determine the fate of chlorinated ethenes in a streambed where a tetrachloroethene (PCE) plume is discharging. Streambed temperature mapping was used successfully to identify the groundwater discharge areas where streambed sediment and water samples were taken. Sediment samples were taken from various locations at different depths to characterize the sediment compositions and total organic carbon (TOC) contents. Water samples were also taken to measure the concentrations of redox-sensitive species as well as concentrations and carbon isotope ratios of PCE and its degradation products.

The local flow conditions as well as TOC contents significantly influenced the local redox conditions. Hydrochemical analysis effectively demonstrated various redox conditions, nitrate-reducing to methanogenic conditions, at the site.

The carbon isotope analysis was crucial to identify the final degradation product at

each location and to distinguish biodegradation from other physical processes. In a high discharge zone under nitrate-reducing condition, no significant biodegradation of PCE was observed. At a location with an intermediate discharge rate under predominantly iron-reducing condition, cis-1,2-dichloroethene (cDCE) was the main compound with constant isotope ratios indicating no further degradation. In contrast, at a location with a very low discharge rate under predominantly sulphate-reducing condition, cDCE and vinyl chloride (VC) became strongly enriched in ^{13}C and ethene was present, suggesting complete reductive dechlorination. Finally, at a location under methanogenic condition with a low discharge rate and a high total organic carbon layer, ethene became enriched in ^{13}C suggesting its further transformation, probably to ethane which was present in the profile. The results demonstrated that even for a relatively small studied area, there was a significant level of spatial variability in terms of discharge rates, redox conditions and extents of PCE degradation, and these factors were closely related to one another.