

**Full-Scale Permanganate Remediation of Chlorinated Ethenes in Fractured Shale:  
Part 1. Site Characterization and Design and Implementation of Full-Scale Remedy**

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During a RCRA Facility Investigation at the Watervliet Arsenal near Albany, New York, groundwater contaminated with PCE and its daughter products was discovered in the fractured shale bedrock aquifer near the site boundary. Extensive site characterization was performed, including installation and sampling of four multilevel monitoring systems (Solinst CMT®, Westbay®, FLUTe®, and Barcad), fracture network characterization via borehole geophysical and hydrophysical logging and interborehole flow testing, rock core VOC subsampling, rock matrix characterization (porosity, permeability, mineralogy,  $f_{oc}$ , diffusion coefficients) and laboratory investigation of matrix interaction with permanganate (rock oxidant demand tests, examination of invasion / reaction mechanisms).

Detailed rock core sampling confirmed high PCE concentrations adjacent to many fractures, providing a basis for the conceptual site model (CSM), where most of the contaminant mass originally present as DNAPL in fractures now occurs as dissolved and sorbed mass in the rock matrix, with back-diffusion acting as the major continuing source of contamination. The selected remedy involves in situ chemical oxidation using sodium permanganate ( $\text{NaMnO}_4$ ), with the objective of reducing the mass flux of contaminants leaving the site boundary.  $\text{NaMnO}_4$  injections were initiated in September 2004 and are planned over a five year period, followed by five years of post-injection monitoring. During the past year,  $\text{NaMnO}_4$  delivery has been impeded by decreased conductivity of injections wells, likely resulting from manganese dioxide precipitate formation either in or near injection boreholes, or in fractures that are hydraulically connected to the boreholes. Injection difficulties have limited the distribution of permanganate in compliance boundary monitoring wells. This presentation will summarize the techniques used to characterize the site, the resulting CSM, the major elements of the full-scale remedy, and lessons learned regarding field application of permanganate in a fractured shale. Part 2 of this presentation will discuss interim remedy performance and future status of the remedial program.

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Beth L. Parker has a Bachelors degree in environmental science/economics from Allegheny College, a Masters degree in environmental engineering from Duke University and a Ph.D. in hydrogeology from the University of Waterloo. She joined the faculty of the Earth Science Department at the University of Waterloo in 1996 and became a professor in the School of Engineering at the University of Guelph in April 2007. Her research involves field studies of transport, fate and remediation of chlorinated solvents in diverse hydrogeologic environments including fractured rock, clayey aquitards, and sandy aquifers.

Tom A. Al is an Associate Professor in the Department of Geology at the University of New Brunswick, Fredericton, New Brunswick, Canada. His research interests include mineral-water reaction processes that affect transport of contaminants in groundwater and surface-water, geochemical and hydrologic processes controlling the release and transport of metals from sulfide-bearing mine waste, and geochemical reaction processes associated with in-situ oxidation of organic contaminants in ground water.