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Chlorinated solvents in groundwater: Field experimental studies of behaviour and remediation*

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Abstract

The chlorinated solvents, such as trichloroethylene, tetrachloroethylene, trichloroethane and methylene chloride have a combination of physical and chemical properties that give them exceptional propensity to cause groundwater contamination. These solvents have been in widespread use in manufacturing and cleaning industries since World War II. Although somewhat diminished in the past decade, industrial use of solvents is still large. Solvents are now one of the most common causes of significant groundwater contamination in industrialized regions of North America and Europe. Because of the importance of chlorinated solvents as an environmental problem and because little was known or understood about the subsurface fate, transport and remediation of these contaminants, the University Consortium Solvents-In-Groundwater Research Program was started in 1988 by a group of universities in Canada and the United States.

Introduction

The University of Waterloo (the lead institution), Colorado State University and the Oregon Graduate Institute are the principal institutions involved in many aspects of the Research Program. The Research Program also has specific collaborative projects with various other institutions including the State University of New York at Buffalo, Queen's University (Ontario), the University of Western Ontario, Stanford University, and the U.S. Geological Survey.

The main thrusts of the current work are the development and assessment of technologies for in situ subsurface remediation of chlorinated solvents above and below the water table; the use of advanced geophysical methods (surface geophysics and borehole geophysics) and mathematical models to assess the spatial distribution of liquid-phase solvents below the water table and progress

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of *in situ* site remediation methods; and the characterization of D-NAPL (denser-than-water non-aqueous phase liquid) transport, distribution and fate in fractured environments.

Emerging technologies

Emerging technologies are technologies that have been in existence for several years but their performance and limitations warrant assessment. Of the many emerging *in situ* technologies that currently exist, the following are the focus of study:

(i) removal of solvents from the vadose and interface zones by vacuum extraction and soil flushing

(ii) removal of free-phase solvents from the groundwater zone by wells and drains with and without chemically induced interfacial-tension reduction by surfactants

(iii) removal of immiscible phase solvents from the groundwater zone by enhanced solubilization induced by surfactant flushing

New technologies

These remedial technologies have been invented by researchers at universities in the Solvent Research Program and are being assessed in the Solvent Research Program. These technologies are unique to the Research Program:

(iv) passive permeable dehalogenation wall for plume cutoff

(v) void-space air sparge wall for plume cutoff

(vi) permeable bioremediation dispersion wall for nearly passive plume cutoff

(vii) destruction of immiscible-phase solvents by chemical oxidant flushing

(viii) control of solvent contamination areas using sealable-joint steel sheet piling.

The emerging and new technologies are studied through a combination of laboratory experiments, field experimental and mathematical models. Most field experiments are conducted on a relatively large scale in an actual sand aquifer located at Canadian Forces Base Borden in Alliston, Ontario, 75 km northwest of Toronto. In these large field-scale groundwater experiments, many of the difficulties and complications that occur at actual industrial sites are represented. Therefore, the experiments have considerable site realism and yet can be controlled very effectively to allow for quantitative scientific assessment.

At the Borden site, unique field experiments involving controlled release or subsurface emplacement of immiscible-phase chlorinated solvents such as tetrachloroethylene and trichloroethylene into an unconfined sand aquifer are in progress. In the initial stages, these experiments allow the movement of the immiscible-phase solvent liquid and dissolved-phase plumes emanating from the liquid to be studied using various monitoring methods and mathematical models. In later stages, the experiments are used to assess *in situ* technologies for restoration of the contaminated aquifer zones. These experiments are full-cycle experiments in the sense that solvents are introduced to the groundwater zone, their behaviour is studied, and ultimately the solvent mass is removed using *in situ* methods. Of the eight emerging or experimental technologies listed above, six have field trials in progress in addition to associated laboratory studies completed or in progress. The two technologies not yet in field trials are scheduled for trials in 1992.

The Research Program includes fundamental experimental and mathematical modelling pertaining to the behaviour of aqueous-phase and gaseous-phase solvents in the vadose zone and the mechanisms by which solvents in the vadose zone cause contamination of the interface zone at the water table. This research also considers avenues for remediation of the interface zone, which is a particularly difficult remediation task because of the conditions at the capillary fringe.

Experiments at the Borden site involving release of free-phase solvents into the aquifer have been made feasible by creation of impervious cells, which are aquifer segments surrounded by vertical cutoff walls. The walls are constructed of sealable-joint steel sheet pile (referred to as Waterloo sheet piling). The joints on conventional sheet piling have been modified (patent pending) to allow water-tight sealants to be injected into the joints after the walls are driven through the sand aquifer into the underlying clay aquitard. Double-walled cells have been installed for maximum environmental protection. The aquifer segments inside the cells are well suited for performance assessments of new or emerging *in situ* technologies for aquifer restoration. Research is directed at determining what cleanup levels are achievable and developing an understanding of what factors enhance or limit technology performance for various remediation technologies.

Waterloo sheet piling was developed to provide environmentally safe conditions for major experiments involving solvent releases to the Borden aquifer. Through success in this research use, possibilities for scaling-up this technology for application to real industrial or waste disposal sites were recognized. Scaled-up feasibility studies are now underway. The technology has several advantages over conventional cutoff walls. Recently, the barrier has been tested to a depth of 47 feet (14 m) at CFB Borden.

The Waterloo barrier provides a contained subsurface environment for the solvent release experiments, and subsequent aquifer restoration research, and also provides a means for installing *in situ* treatment walls in the Borden aquifer. An *in situ* treatment wall is a vertical wall of permeable material (a narrow trench) placed across a plume. The purpose of the wall is to induce processes, usually chemical or biochemical reactions, that remove contaminants from the plume so that the plume, in effect, is cut off by the wall. To construct a treatment wall the sheet piling cell is driven into the aquifer across or in front of the plume, the cell is dewatered, the aquifer material is removed and replaced with a new reactive material, or with a material or void space of much higher permeability suitable for hydraulic manipulation or air sparging. The sheet piling is then removed from the ground.

The first *in situ* treatment wall to be assessed in the field is a dehalogenation wall. The dehalogenation wall, incorporating catalysed abiotic dehalogenation of chlorinated organics, is currently being evaluated in the remediation and control of a contaminant plume emanating from an emplaced mass of three solvents (TCE, PCE, and TCM) at the Borden site. A biodegradation dispersion wall, which allows for the creation of conditions favourable for the biodegradation of organic contaminants in the subsurface within and downgradient of the wall, is also in place at the Borden site awaiting the start-up of an experiment. An air sparge wall is being designed; the wall will facilitate the introduction of air to a groundwater-zone plume contaminated with volatile organic compounds, with the intent of stripping the VOCs from the plume as it passes through the wall, without disturbance to the plume by pumping. When successful, *in situ* treatment walls offer advantages such as less wastage of clean water and energy and lower long-term cost.

Conclusion

The Borden site is a convenient facility, both with regard to logistics and degree of hydrogeologic complexity, for conducting prototype-scale remediationresearch. If a new or emerging remediation technology cannot be made to function successfully at the Borden site, it can usually be concluded that the technology is not sufficiently advanced for success to be achieved elsewhere.