Fate and transport of pollutants in freezing soil and the application of geoenvironmental centrifuge physical modelling

Mazyar Zeinali, Deborah J. Goodings, and Alba Torrents
Department of Civil and Environmental Engineering
University of Maryland, College Park MD 20742, USA

ABSTRACT. It is essential to understand the dominant features of fate and transport of pollutants released into soil, in order to plan effective engineering response, including containment and remediation. Significant progress has been made in understanding mobility of pollutants in unfrozen soil, however, surprisingly little is understood about mobility in a freezing environment in which behavior will be dramatically different. Processes that govern fate and transport of contaminants in unfrozen ground are reviewed. Effects of freezing on that contaminant fate and transport are discussed, but remain largely unknown. The next body of research must involve experimental investigations into full system response to identify at once the overall behaviour and the dominant factors that dictate that behaviour. Full scale tests are desirable, but their size and duration make them impractical for initial parametric studies. Geoenvironmental centrifuge modeling is identified as a powerful alternative using small, short duration physical models that capture the essential self-weight driven influences missing from conventional small model testing.

Contents

Introduction

The soil environment is a multifaceted system consisting of complex compartments that include biota, solid, liquid, and gas phases. When a contaminant is introduced into this environment, it can move through the soil by a combination of physical processes including dispersion, diffusion, and advection. In addition, it can interact physically or chemically with any and/or all compartments, of which sorption processes are central for pollutant transport. Sorption onto particle surfaces can limit movement or the particles can act as source for the contaminant through release or desorption (the reverse process of sorption), allowing re-entry into the pore fluid either in solution or as colloids. Reliable data on these interactions is needed for the engineering prediction of transport and design of remedial methods. With such a high degree of heterogeneity and different processes at work, predicting pollutant movement is a daunting task to say the least. Notwithstanding that complexity, significant progress has been made in understanding fate and transport of pollutants in unfrozen soil. However, surprisingly little is understood about the effect on those processes of a freezing environment.

Understanding whole system response, rather than isolated element response, is essential for effective planning of containment and remediation measures under any conditions. In certain respects, data of pollutant transport gathered from the field provides the best information on transport processes, although the lack of experimental control creates difficulty in identifying the effects of individual components, to relate the information to other sites. Full scale laboratory studies are a possible alternative, however these are typically difficult to handle because of their huge size, and the times for development of prototypical seepage conditions will often require years. Environmental experimentalists and numerical modellers are left, then, to work together to assemble acceptable predictions of these events. They develop those predictions primarily from isolated pieces of the puzzle derived typically from laboratory tests that do not simulate field conditions, and certainly do not capture whole system response. Because the freezing process has a very major influence on contaminant mobility, this makes the task of fitting together what is known of uncontaminated soil freezing processes, with what is known of fate and transport of contaminants in unfrozen soil, very difficult indeed when whole system response is not known.

The option of using conventional small scale physical models of a whole system is unsuccessful because in the absence of recreating full scale stresses in those small models they fail to capture essential interactions of soil freezing which is known to exert strong influence on fluid transport. Small scale centrifuge modelling of contaminant transport is emerging as a new and powerful