released into cooling and freezing ground will complicate an already complex event. It is possible to study each of these possible effects individually using small, isolated elements of soil, however this poses a major problem in assembling the composite picture of the combined effects. With respect to the freezing alone, Konrad and Seto (1994) observed that local, self-evolving, internal conditions of pore pressures, temperature gradients, soil overburden pressures, and soil compressibility within a full height soil column are essential factors in the development of fluid flow, and ice development. In addition, Henry (1988) concluded that individual conflicting effects of solutes on fluid migration during freezing may combine to produce quite different whole system consequences depending on concentration, initial distribution, and other environmental factors. To understand the dominant mechanisms, then, it is essential to study whole system response first. This can either be undertaken with a full scale soil column in a real time experiment where 6 months of freezing and cooling requires a 6 month long experiment. Or it can be undertaken in a small scale model tested, including the freezing process, while accelerated on a geoenvironmental centrifuge, to bring into similarity all fluid flow and soil self-weight factors. In that model, all heat flow and fluid movement will develop to scale and will occur faster by a factor of (the model scale)^2, so that processes taking place over 6 months in real time may be simulated in 4.9 hours in a model of scale 1:30 tested at 30g.

The idea of modeling uncontaminated soil freezing on the geoenvironmental centrifuge was first hypothesized by Miller and Miller (1956) based on their experimental and theoretical work in soil freezing. The primary attraction of centrifuge modeling lay not so much in the reduction of the size of the soil column being tested, since soil freezing seldom penetrates more than 1m in seasonally frozen soil, but rather in the radical reduction in duration of experiments. Yang & Goodings (1998) confirmed that models of columns of uncontaminated soil frozen at 1g constructed at different scales cannot simulate full scale freezing effects in a much larger (1g) soil column. However, when they froze the same size columns under increased accelerations on the geoenvironmental centrifuge, to make all stress conditions simulate a single full scale soil column, model columns constructed to different scales all simulated the same full scale freezing event, thereby confirming Miller and Miller's hypothesis. Yang & Goodings further confirmed the significance to the freezing processes of simulating realistic temperature regimes, as Konrad and Seto stressed.

Many centrifuge model studies of contaminant migration without sorption, and without freezing have been successfully completed by various researchers (see, for example, Arulanandan, et al., 1988; Illangasekare et al., 1991; Hellawell and Savvidou, 1994; Hensley & Schofield, 1991; Hensley & Randolph, 1994; and Griffioen & Barry, 1998; Savvidou, 1988; Hensley and Savvidou, 1993). Only Gurung *et al.* (1998) have used the geoenvironmental centrifuge to explore modelling of sorption, conducting rapid tests of conventional breakthrough columns. They studied the migration of zinc through dredge soil models using a centrifuge operating at 50 g. In analyzing their results, they used a modified form of equation 4 with n=1, and found a good correlation ($R^2>0.99$) for their experimental data, from which they concluded that centrifuge modelling of sorption of zinc was valid for their test conditions. Although this is not proof for all pollutants in all soils, it serves to establish the potential.

Only Han *et al.* (1999) have modelled contaminant transport in freezing soil. Their contaminant was a simple, but nonetheless interesting, non-sorbing fluid: ethylene glycol, or antifreeze. They simulated a 6 month period of freezing and thawing, releasing the ethylene glycol from a buried reservoir into pure silt with no organic content. They initiated the release at different times during freezing. Patterns of transport varied according to the relationship between the moment of contaminant release and the depth of freezing that had occurred. When the ethylene glycol was released with no subsequent freezing, the contaminant was trapped in the soil pores surrounding the reservoir. When the ethylene glycol was released after freezing had penetrated well below the reservoir, the effect was similar. When the ethylene glycol was released, followed immediately by the initiation of freezing, the contaminant was drawn upward to the soil surface in a distinct plume. Patterns of behavior, in retrospect, are explainable. They were not, however, predictable. Although these models were only preliminary in nature and largely qualitative, they highlighted new, unanticipated patterns of behavior, and at the same time, established a precedent for the application of centrifuge modeling in contaminant transport in freezing soils.

Summary and Conclusions

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