



Fig. 1. Freundlich isotherm for values $n=1$, $n<1$, and $n>1$

laboratory tool to simulate realistic, and therefore complex whole system environmental response quickly. It involves simply taking the conventional small scale model, and conducting the same freezing and contaminant release test while the model, of scale 1:N is subjected to N times earth's gravity to bring into similarity all self-weight fluid and soil stresses. In unfrozen soils, centrifuge models have been used successfully to explore transport of non-sorbing contaminants driven by self-weight, capillary tension, concentration gradients, temperature gradients, and pressure gradients, but not involving the chemical processes of sorption. In uncontaminated soil, they have been used to examine the interaction between freezing, subsequent warming, and resulting fluid transport.

The object of this paper is twofold: to consider the effects of soil freezing on fate and transport of contaminants through soil; and then to consider the application of centrifuge modelling to study this problem.

Sorption as an Equilibrium and Non-Equilibrium Process

Sorption is the transfer of molecules from the solution phase into the solid phase and encompasses both adsorption (partitioning onto surfaces) and absorption (penetration into the subsurface). Generally, the sorption of a pollutant at equilibrium onto a particle surface can be described by the Freundlich isotherm (Equation 1). The Freundlich

equation is empirical and yields useful information about the sorption reaction. In this isotherm, the amount of pollutant adsorbed onto the particle surface (q) is dependent on the total pollutant concentration in solution (C). Here, K_F is known as the Freundlich equilibrium constant (a measure of sorption capacity of the sorbing surface and the pollutant being sorbed) and n is a measure of the nonlinearity (or sorption intensity) of the sorption process.

$$q = K_F C^n \quad [1]$$

Figure 1 illustrates this general relationship for any pollutant. As shown, three general types of curves are observed. For $n=1$, the adsorption is linear and there is no change in the attraction of the pollutant to the surface as a function of concentration. At higher concentrations, in the case where n is less than 1, a decreasing percentage of the pollutant will sorb to the surface as the concentration of the pollutant increases. This could be due to a variety of reasons including the reduction of the number of available reactive sites. And finally, in the situation where n is greater than 1, pollutant adsorption increases with increasing solution concentration. In this relationship, q can be predicted for other concentrations once K_F and n are identified. However, in order to predict movement through a whole system, rather than at a single point, additional