6.3 Solute Transport: Theoretical Background

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The transport of solutes in soils has always been of interest in agronomy because of the impact that nutrient and salt concentrations have on conditions for plant growth. During the last few decades, interest in solute transport has broadened due to concerns about the fate of chemicals in the subsurface environment, particularly with regard to the possible contamination of soil and groundwater by agricultural and industrial chemicals. Although significant progress has been made, the quantitative description of solute transport in soils remains a challenging and active area of research.

In this section we review basic theoretical concepts and models for solute transport in soils (miscible displacement). Later sections discuss experimental procedures (Section 6.4) and methods of data analysis (Section 6.5).

6.3.1 Elementary Concepts

6.3.1.1 Solute Transport Experiments

It is useful to first consider the general character of solute transport experiments before delving into specific theoretical transport models. Our discussion follows that of Nielsen and Biggar (1962) and Danckwerts (1953). Suppose a column packed with soil is attached to a water reservoir such that water flows through the column at a steady volumetric rate Q (Fig. 6.3–1). The volume of water in the column, V, is referred to as the *pore volume*. This terminology is used for both water-saturated and water-unsaturated columns, even though in the unsaturated case V is not equal to the total pore space as the name suggests (*pore water volume* is a more precise term, but it is not used). Now suppose that the column's inlet reservoir, which originally contains no solute, is suddenly switched to an identical reservoir with solute concentration c_0. Solute flows into the column and is transported through the soil, eventually exiting the soil and column in the column's effluent (outflow). If we monitor the solute content of the effluent, we find that the sharp increase in solute concentration we imposed at the inlet does not materialize at the outlet. Instead, the effluent concentration increases gradually with time. The sharp front is diffused because individual solute particles take a variety of tortuous pathways through the soil, with some pathways being faster or slower on average. The time required for an individual particle to traverse the column is called the *residence time*. A plot of the effluent concentration as a function of time, $c_e(t)$, reflects the distribution of residence times in a column. The plot is called the *breakthrough curve*. Breakthrough curves are commonly represented using dimensionless variables. The normalized