SOIL-WATER CHARACTERISTIC CURVES

Hydraulic conductivity $K(\theta)$ relates velocity and hydraulic gradient in Darcy's law. Moisture content θ is defined as the ratio of the volume of water to the total volume of a unit of porous media. To complicate the analysis of unsaturated flow, both θ and K are functions of the capillary suction ψ. Also, it has been observed experimentally that the θ–ψ relationships differ significantly for different types of soil. Figure 9.2a shows the characteristic drying and wetting curves that occur in soils that are draining water or receiving infiltration of water. The nonlinear nature of these curves for several selected soils are shown in Figure 9.2b. The curves reflect the fact that the hydraulic conductivity and moisture content of an unsaturated soil increase with decreasing capillary suction. The sandier soils show a very different response compared to the tighter loam and clay soils.

Some simple empirical expressions used to relate water content of a soil to the capillary pressure head include the one from Brooks and Corey (1964)

$$\theta = \theta_r + (\theta_s - \theta_r)(\psi/\psi_b)^{-\lambda} \tag{9.3}$$

where

θ	=	volumetric water content
θ	=	volumetric water content at saturation
θ_r	=	irreducible minimum water content
ψ	=	matric potential or capillary suction
ψ_b	=	bubbling pressure
λ	=	experimentally derived parameter

Brooks and Corey (1964) also defined an effective saturation, S_e, as

$$S_e = \frac{S_w - \theta_r}{1 - \theta_r} \tag{9.4}$$

where $S_w = \theta/\theta_s$, the saturation ratio.

Van Genuchten (1980) also derived an empirical relationship between capillary pressure head and volumetric water content, defined by

$$\theta = \theta_r + \frac{\theta_s - \theta_r}{\left[1 + (\alpha\psi)^n\right]^m} \tag{9.5}$$

where α, m, and n are constants. Generally, these equations work well for medium- and coarse-textured soils with predictions for fine-textured materials usually being less accurate. These equations are often used in computer models to represent soil characteristics for flow in the unsaturated zone. For large capillary heads, the Brooks and Corey and Van Genuchten models become identical if $\lambda = mn$ and $\psi_b = 1/\alpha$.

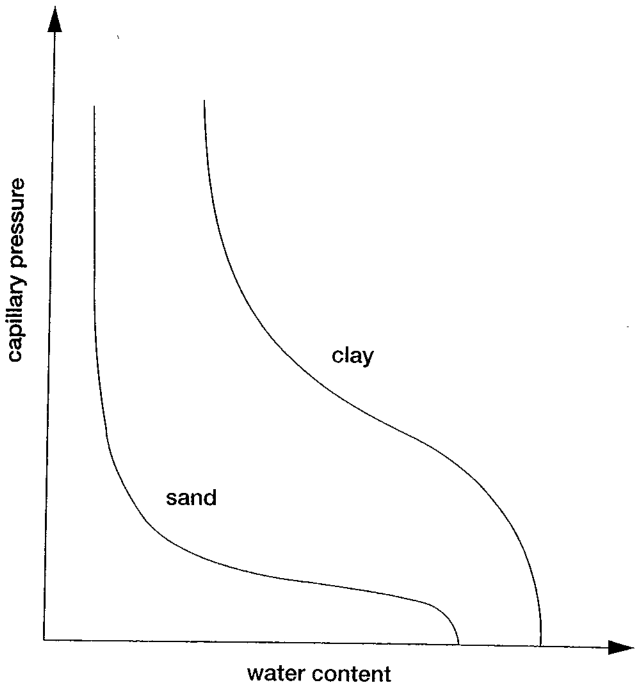


FIGURE 4.2.1 Typical characteristic curves for sand and clay soils

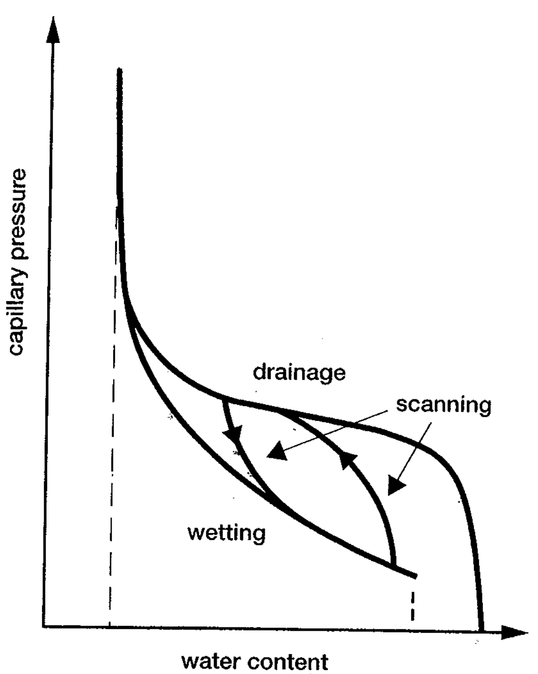


FIGURE 4.2.2 Soil water characteristic curve showing drainage, wetting and scanning curves

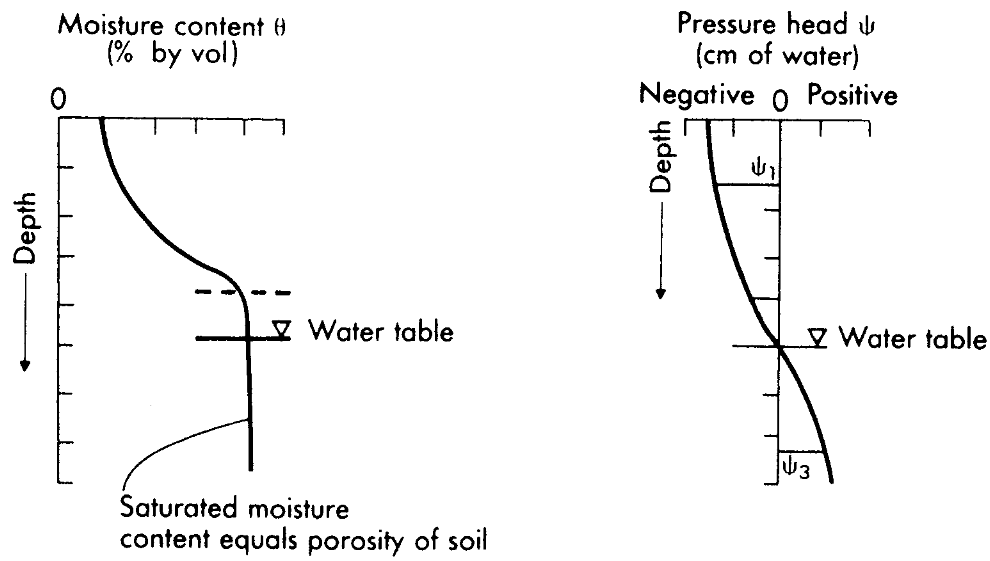
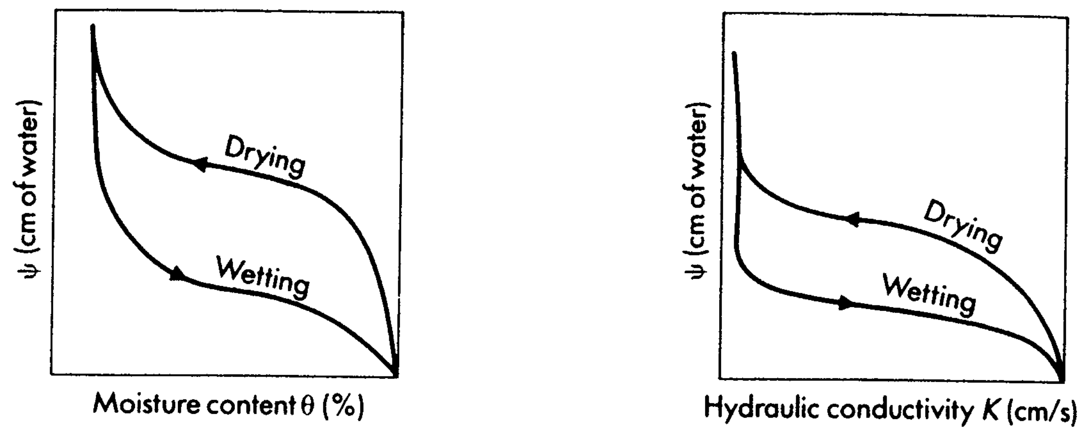
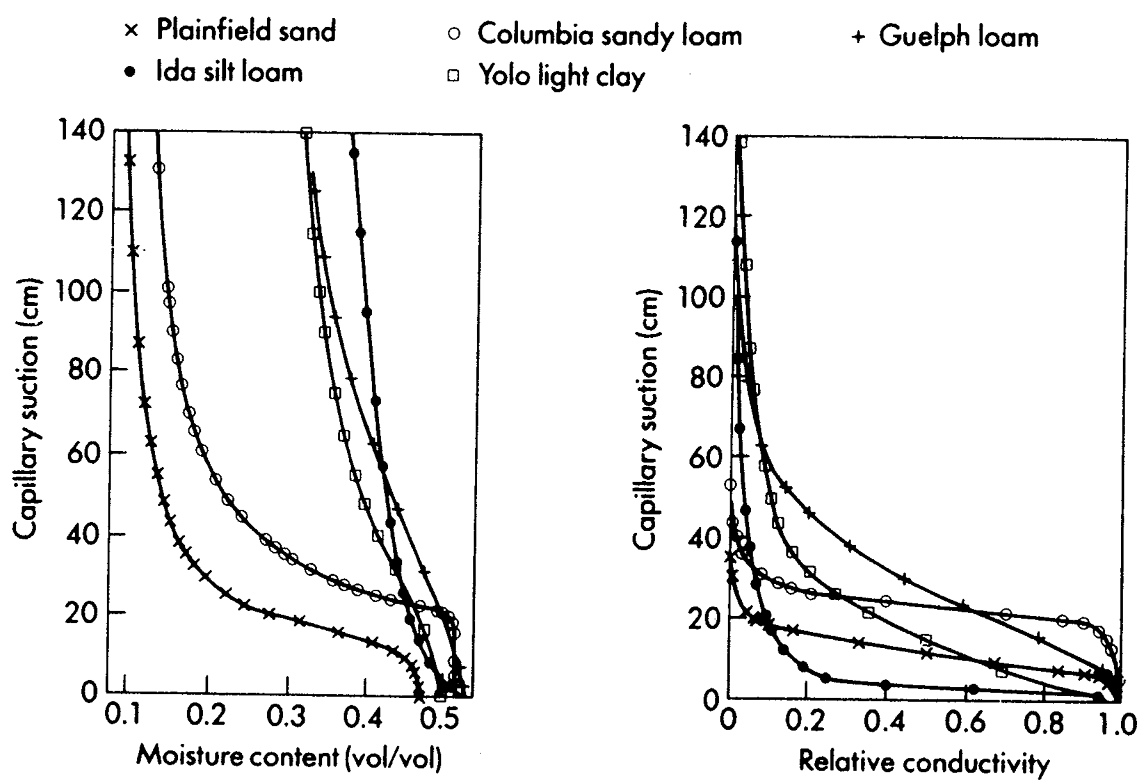


Figure 9.1 Typical θ and ψ relationships with depth in the unsaturated zone.



(a)



(b)

Figure 9.2 Soil characteristic curves for (a) wetting and drying and (b) different soil types

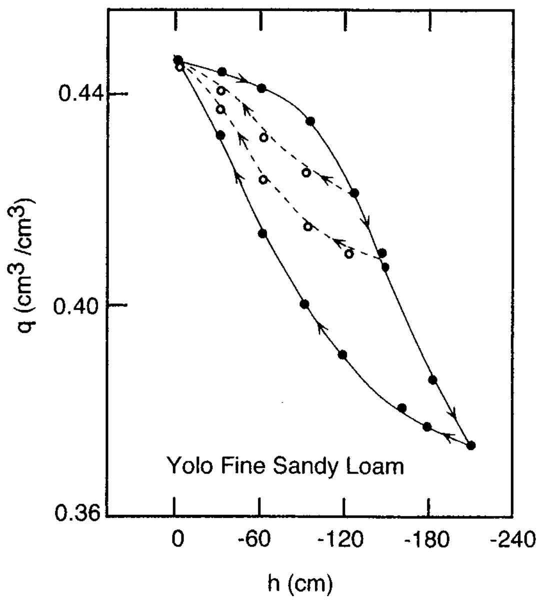


Figure 9.3 Water retention curves for a sample of Yolo fine, sandy loam. The solid curves are eye-fitted through measured data along the two main boundary curves. Dashed curves represent primary wetting scanning curves. Arrows indicate the direction at which the pressure head changes are imposed. Source: Nielson et al., 1986. © American Geophysical Union.

A drying curve occurs when one allows an initially saturated sample to desorb water by applying suction. If the sample is then resaturated with water, thus decreasing the suction, it will follow a wetting curve. The fact that the drying curve and the wetting curve will generally not be the same produces the hysteretic behavior of the soil water retention curve as illustrated in Figure 9.3. The soil water content is not a unique function of capillary pressure, but depends on the previous history of the soil. The hysteretic nature of θ is due to the presence of different contact angles during wetting and drying cycles, and to geometric restrictions of single pores (Nielsen et al., 1986). For example, the contact angle between the water and the soil surface is greater during the advance of a water front than during its retreat.

UNSATURATED HYDRAULIC CONDUCTIVITY

Evidence suggests that Darcy's law is still valid for unsaturated flow except that hydraulic conductivity is now a function of moisture content. Darcy's law is then used with the unsaturated value for K and can be written

$$v = -K(\theta)\,\partial h/\partial z \tag{9.6}$$

where v is darcy velocity, z is depth below surface [L], ψ is tension or suction [L], $K(\theta)$ is unsaturated hydraulic conductivity [L/T], h is potential or head ($h = z + \psi$) [L/T], and θ is volumetric moisture content.

Unsaturated hydraulic conductivity can be determined by both field methods and laboratory techniques, both of which are time-consuming and tedious. Estimates are often made from soil parameters obtained from soil-water retention relationships such as those from Brooks and Corey (1964) and Van Genuchten (1980). Figure 9.4 shows observed values and calculated curves for relative hydraulic conductivity as a function of capillary pressure.

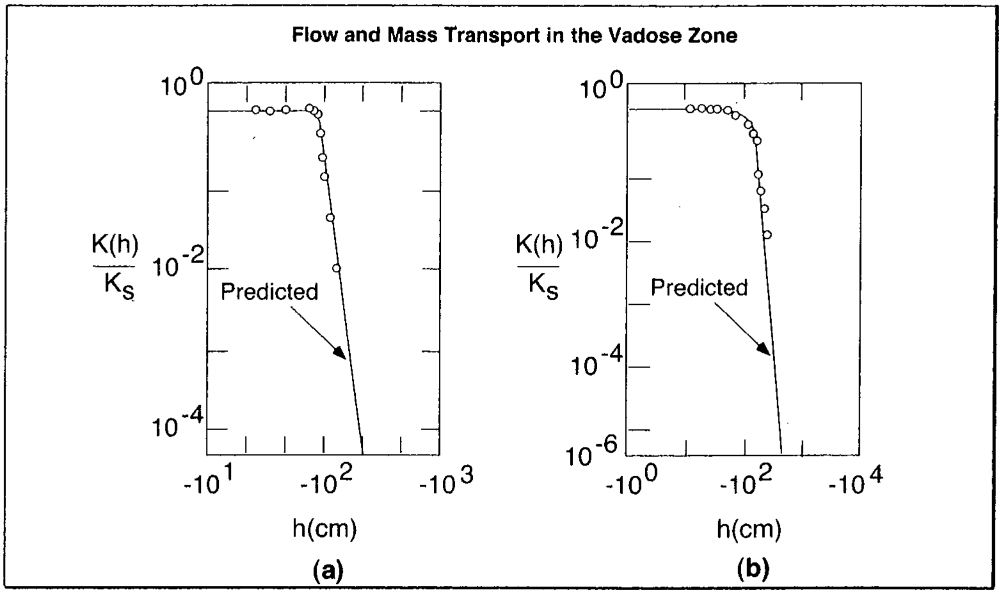


Figure 9.4 Observed values (open circles) and calculated curves (solid lines) for relative hydraulic conductivity of (a) Hygiene sandstone and (b) Touchet silt loam. Source: Van Genuchten, 1980.