SOIL SCIENCE 322
PHYSICAL PRINCIPLES OF SOIL AND WATER MANAGEMENT

SOIL WATER POTENTIAL

Read: pages 142 to 172 in Environmental Soil Physics

The two forms of energy (energy—the ability to do work) influencing water flow in soil are: potential and kinetic. Soil water velocities are slow, thus the kinetic energy (KE--the energy which matter has by virtue of its motion: $KE = 1/2\ mv^2$, $KE \propto v^2$) is generally considered to be negligible. Thus, the potential energy is the primary energy source determining the state and movement of water in a porous system (soil). The potential energy is determined by the water position and/or internal condition. There is a spontaneous and universal tendency for all matter to achieve a state of low potential energy. Accordingly, soil water flows (from high to low) in the direction of decreasing potential energy.

The Energy Status of Soil Water

The absolute amount of energy that a body of water may contain cannot be determined. (Absolute energy includes electronic and nuclear bonding energies as well as kinetic energy and energy derived from cohesive and adhesive forces and potential energy resulting from elevation).

Potential Energy, PE

Potential energy (PE) is the energy which a body has by virtue of its position in a force field.

Forces Associated with the Potential Energy of Water in Soils

In soils, the water is acted upon by many force fields, thus the total potential, Φ_t, is a summation of these force fields:

$\Phi_t = \Phi_g + \Phi_p + \Phi_o$ the subscripts are defined as following: t, total; g, gravity; p, pressure; and o, osmotic

in other literature and textbooks this will be expressed as: ..$\psi_t = \psi_g + \psi_p + \psi_o$.

Gravitational Potential

The gravitational potential, Φ_g, arising from the earth’s gravitational field, i.e. each earthly body is attracted toward the earth's center by a gravitational force equal to the weight of that body.

1. The position of the point under consideration relative to the elevation of the reference level determines whether the ψ_g is positive or negative.

2. The gravitational potential becomes greater as the elevation above the reference pool increases.

Pressure Potential — (includes positive Φ_p and negative Φ_m potentials where m relates to soil matric.)

The positive potential is termed pressure potential, submergence potential, piezometric head, etc.; we will refer to it as the pressure potential, Φ_p. It is due either to the weight of water at a point under consideration or to gas pressure which is different from that which exists at a reference position.

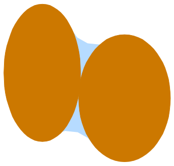
The pressure potential (Φ_p) is a measure of the positive pressure potential and is measured in saturated soil conditions (with the exception of entrapped air). When measuring the Φ_p below a free water surface (water table), the change in Φ_p with depth is equal and opposite to the change in Φ_g.

The negative pressure potential has been referred to as capillary potential, tension, suction, and matric potential, Φ_m. We will use the term matric potential. The matric potential results from the capillary and adsorptive forces due to the soil matrix.

The matric potential is a negative pressure and is measured in unsaturated soil. As a soil wets up, Φ_m increases from a very low (negative) value to zero. If a completely dry soil is exposed to an atmosphere containing water vapor, a single layer of water will be adsorbed on the surfaces (by hydrogen bonding) and this water will be held very strongly (will have very low potential energy). This occurs at a relative humidity (RH) of about 35 to 40%. At the same time, or even before, any soluble ions in the soil will hydrate (will sorb one layer of water molecules).

As the RH is increased, additional layers of water are adsorbed in an ice-like structure (less dense than liquid water). The second layer of water is completed at about 60% RH. As the RH is raised to between 98 and 99%, the layer of adsorbed water becomes thick enough that the layers coalesce at points of contact between particles, and surface tension forces become important.

As more water is added, crevices start to fill, then pores, small ones first, then medium, then large. Potential energy of the water becomes greater as the radius of curvature of the water films in the crevices and pores becomes greater (as water content increases). At saturation the potential energy relative to a reservoir of soil solution at the same elevation is zero.

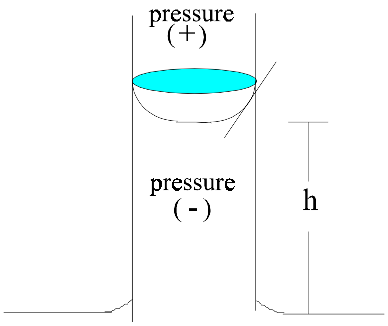


Capillary Model (This is presented to help you understand negative potential)

Assume water is crawling up the wall of a capillary tube because of (1) adhesion of the water molecules to the wall and (2) cohesion of other water molecules to those adhering to the wall (see Fig. 3). If the adhesive forces are greater than the cohesive forces, water will rise up the tube until the cohesive forces (surface tension) of the liquid around the perimeter of the tube will not support a heavier water column. At this point, the surface tension forces are supporting the column (downward force = $\pi r^2 h \rho_w g$) around a perimeter of $2\pi r$, where r = radius of tube, h = height of water column, ρ_w = density of water, g = acceleration of gravity. The supporting force is then the surface tension, σ, acting over a perimeter of $2\pi r$ and this force is equal to the downward force:

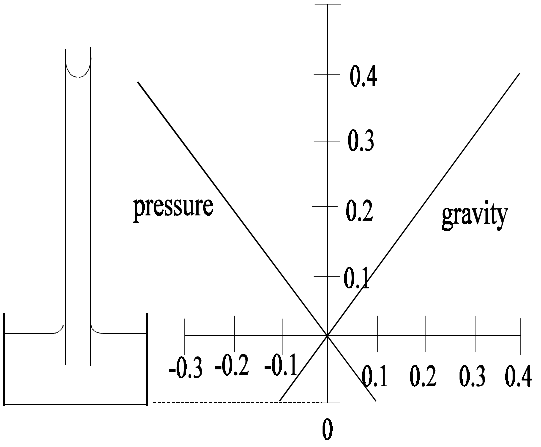
<u>Upward force</u> <u>Downward force</u>

$$2\pi r\sigma\cos\alpha = \pi r^2\rho_w hg$$



Capillary rise model

1. This figure is a case where we see there is no flow



2. Pressure in the container increases with depth from zero at the water surface to a positive 0.1 m at the container bottom. The pressure potential is equal but opposite to the gravitational potential.

3. Similarly, the pressure potential in the capillary tube decreases with height to compensate for the increasing gravitational potential.

Osmotic Potential

The osmotic potential, Φ_o, results from the hydration of ions in the soil solution. The polar nature of water, with two sites that are electropositive and two that are electronegative, causes water molecules to be attracted to ions in the soil solution. These attractive forces tend to orient water molecules around ions and the Φ_o refers to the work required to pull water away from these ions. In order for an osmotic pressure to develop due to differences in osmotic potential, diffusion of solute particles from high to low concentration regions must be prevented (by a semi-permeable membrane or electrostatic charge) but water molecules must be able to cross the membrane.

Soil salinity affects plant growth through osmotic effects. Uptake of water by plants requires that osmotic potential inside root cells be lower than the total water potential (of which osmotic potential is a part) in the soil solution. Turgidity of plant cells is due to osmotic pressure.

Swelling pressure of montmorillonite clay is due to osmotic pressure resulting from the difference in solute concentration in the solution between clay plates (held by cation exchange charge) and the bulk solution.

Osmotic pressure (potential) is the result of the dipolar nature of water molecules. Ions in solution are attracted by the electric field around individual water molecules.

Osmotic potential is given by:

$$pV = nRT$$

$$c = n/V$$

c = molar concentration, T = temperature, V = volume, R = gas constant, n = number of moles, and p = pressure.

$$p = cRT \quad \text{or} \quad \psi_o = cRT$$