Reference:

Loewe F. 1956 Contributions to the glaciology of the Antarctic J. Glaciology 2 pp 657-665

22 August 1957

Heat and Water transfer in Soils

by D.A. de Vries

C.S.I.R.O. Division of Plant Industry, Deniliquin, N.S.W.

The processes of heat and water transfer in soils influence the boundary conditions for heat and water flow at the lower limit of the atmosphere. These processes are therefore of importance in the study of both the microclimate and macroclimate (energy balance, transformation of air masses). The experimental and theoretical investigation of these phenomena has advanced rapidly during the past ten years.

Water moves in the soil in the liquid and in the vapour phase. Liquid transfer is governed by Darcy's law (Baver, 1956), which can be written:

$$q_l = -\rho_l K \nabla \Phi = -\rho_l K \nabla \psi - \rho_l K k \qquad (1)$$

where q_l (g cm^{-2} sec^{-1}) is the liquid flux density, ρ_l (g cm^{-3}) the density of liquid water, Φ (cm) the hydraulic head and K (cm sec $^{-1}$) the hydraulic conductivity. $\Phi = \psi + z$ where ψ (cm) is the pressure head and z (cm) the gravitational head. If atmospheric pressure is taken as the datum for ψ this quantity is positive below the water table and negative above the water table. k is a unit vector in the z-direction (positive upwards). In unsaturated soil both ψ and K decrease rapidly with decreasing moisture content.

Movement in the vapour phase is a process of diffusion of water vapour in the air-filled pores. The vapour flux density, q_v (g cm^{-2} sec^{-1}) can therefore be expressed as:

$$q_v = -D_v \nabla \rho_v \qquad (2)$$

where ρ_v (g cm^{-3}) is the vapour density and D_v (cm^2 sec^{-1}) a generalized diffusion coefficient (Philip and de Vries, 1957). The vapour density can be written as:

$$\rho_v = \rho_0 h = \rho_0 \exp(g\psi/RT) \qquad (3)$$

where ρ_0 is the saturation vapour density and h the relative humidity of the soil air. The latter is related to ψ and therefore also to the moisture content. g (cm^2 sec^{-1}) is the acceleration of gravity, R (erg g^{-1} ^{o}K^{-1}) the gas constant for 1 g of water vapour and T (^{o}K) the absolute temperature.

Heat transfer in soils is primarily a process of heat conduction, but water movement also contributes to the heat flow mainly by transfer of latent heat (de Vries, 1952). The heat flux density q_h (cal cm^{-2} sec^{-1}) can be expressed as follows:

$$q_h = -\lambda \nabla T + L q_v \qquad (4)$$

where λ (cal cm^{-1} sec^{-1} ^{o}K^{-1}) is the thermal conductivity and L (cal g^{-1}) the heat of vaporization of water.

From equations (1) to (4) simultaneous differential equations can be derived with the moisture content and the temperature as independent variables (Philip and de Vries, 1957). These equations are non-linear and for their solution one must have recourse to numerical methods.

Infiltration is mainly governed by moisture movement in the liquid phase under the influence of gravity and gradients of moisture content (Philip 1957 a,b). So is evaporation from bare soil at evaporation rates on the order of 10^{-6} cm sec^{-1} or more (Philip, 1957 c; de Vries 1957). Under natural conditions vapour flow in the soil due to temperature gradients is of the order of 10^{-7} cm sec^{-1} or less.

For further meteorological and hydrological implications of these principles the reader is referred to the literature cited below, which also contains many references to earlier work.

References:

Baver L.D.	1956	Soil Physics, John Wiley and Sons, New York
Philip J.R.	1957a	The physical principles of soil water movement during the irrigation cycle, Proc. 3rd Int. Cong. Irrig. Drainage 8, pp. 126-153
Philip J.R.	1957b	The theory of infiltration 1, Soil Science, 83, pp. 345-357
Philip J.R.	1957c	Evaporation and moisture and heat fields in the soil, J.Meteorology 14 (August 1957)
Philip J.R. and Vries, D.A. de	1957	Moisture movement in porous materials under temperature gradients. Trans. Amer. Geophys. Union 38, pp. 222-232
Vries D.A. de	1952	The thermal conductivity of granular materials, Annexe 1952-1 au Bulletin de L'Institut International du Froid, Paris pp. 115-131
Vries D.A. de	1957	Soil water movement and evaporation from bare soil Proc. 2nd Aust. Conf. Soil Sc., paper No. 48