Forest Hydrology: Lec. 13

Lecture content

- Transpiration
    - The Penman-Monteith equation and the big leaf approach

Transpiration

Penman-Monteith and the **big leaf approach**

The Penman-Monteith equation is based on a combination of a simplified energy balance equation for the surface and equations for the transport of sensible heat and latent heat away from the surface. It is what has been called a **big leaf model**, in that there is an assumption that a complex vegetation canopy can be represented as if it were acting as a single transpirating surface at some effective height above the ground.

Sensible heat exchange

The sensible heat flux is a function of the temperature gradient in the air above the vegetation canopy.

$$H = \frac{1}{r_{a,H}} \rho_a c_p \left(T_0 - T_z \right)$$

where

H	= sensible heat flux
$r_{a,H}$	= aerodynamic resistance
ρ_a	= density of the air
c_p	= specific heat capacity of the air
T_0	= temperature at the surface
T_z	= temperature at height z

Latent heat exchange

The latent heat flux is a function of the vapor pressure gradient in the air above the vegetation canopy.

$$L = \frac{1}{r_{a,V}} \frac{\rho_a c_p}{\gamma} \left(e_0 - e_z\right)$$

where

- L = latent heat flux
- $r_{a,V}$ = aerodynamic resistance to the transport of vapor
- e_0 = vapor pressure at the effective canopy surface
- e_z = vapor pressure at height z
- γ = psychrometric constant (66 Pa/ K)

Problems …and solutions - 1

The problems with these equations is that the temperature and vapor pressure at the surface (of the leaf) are not easily measured

Monteith (1965) came up with the idea of using an additional conceptual expression for the transport of vapour from the interior of stomata of the leaf surfaces to the free air, as

$$L = \frac{1}{r_c + r_{a,V}} \frac{\rho_a c_p}{\gamma} \left(e_s(T_0) - e_0 \right)$$

where

r_c = effective stomatal resistance for the canopy as a whole

$e_s(T0)$ = saturated vapor pressure at the surface temperature T0.

Problems …and solutions - 2

Combining these expressions allows the unknown vapour pressure at the conceptual big leaf surface to be eliminated such that

$$L = \frac{1}{r_c + r_{a,V}} \frac{\rho_a c_p}{\gamma} \left(e_s(T_0) - e_z \right)$$

There is still the problem of estimating $e_s(T_0)$.
This is done by assuming that this value can be approximated by the expression $e_s(T_z)+\Delta_e(T_0-T_z)$.
In most applications a further approximation is made: that the aerodynamic resistances can both be made equal to the equivalent resistance for momentum transport in a well-mixed neutral boundary layer for which a value can be derived from assumptions about the wind speed profile.

Problems …and solutions - 3

After these approximations

$$L = \frac{1}{r_c + r_a}\frac{\rho_a c_p}{\gamma}\left[e_s(T_z) - e_z + \Delta(T_0 - T_z)\right]$$

But from the expression for sensible heat flux

$$\left(T_0 - T_z\right) = \frac{H r_a}{\rho_a c_p}$$

Problems …and solutions –
The Penman-Monteith equation

We therefore obtain

$$L = \frac{1}{r_c + r_a}\left\{ \frac{\rho_a c_p}{\gamma} \left[e_s(T_z) - e_z \right] + \frac{\Delta r_a}{\gamma} H \right\}$$

Which can be rearranged, taking into account the energy balance equation, to provide

$$L = \frac{\Delta R_n + \rho_a c_p \left[e_s(T_z) - e_z \right] r_a}{\Delta + \gamma(1 + r_c / r_a)}$$

Problems …and solutions – The Penman-Monteith equation

Use of the equation requires measurements of Rn, temperature, humidity and wind speed at the reference height z, and estimates of two resistance coefficients, r_a and r_a.
The equation can be applied with hourly data to provide estimates of the diurnal pattern of evapotranspiration rates.

The resistance coefficients have an important control on predicted evapotranspiration rates, particularly when the resistances are low. Typical values for a dry grass canopy would be ra=rc=50 s/m and for a dry tree canopy ra= 10 s/m and rc=50 s/m.
The highest value of ET rates will be predicted for a rough canopy (low ra), with intercepted water on the leaf surfaces (rc=0).