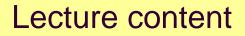
Forest Hydrology: Lec. 12



Evaporation

- Diffusion and the Fick's law
- Dalton law
- Penman combination equation

Basic principle

Fick's Law: A diffusing substance moves from where its concentration is larger to where its concentration is smaller at a rate that is proportional to the spatial gradient of concentration

 $dC \leq \mathbf{K}$

indicates movement from regions of higher concentration to regions of lower concentration where gradient (change) in concentration

will have units of substance *[L T⁻¹]

 $F_z(X)$ = rate of transfer of substance X in z direction \leftarrow

 $F_z(X) = -D$

- D_X = diffusivity of substance X [L² T⁻¹]
- C(X) = concentration of X \leftarrow units depend on substance

Evaporation

Fick's Law: A diffusing substance moves from where its concentration is larger to where its concentration is smaller at a rate that is proportional to the spatial gradient of concentration

$$E = K_E v_a \bullet_s - e_a \quad \longleftarrow \quad \Box$$

finite difference approx.

where

- E = evaporation rate [L T⁻¹]
- K_E = efficiency of vertical transport of water vapor [L T⁻¹ M⁻¹] v_a = wind speed [L T⁻¹]
- e_s = vapor pressure of evaporating surface [M L⁻¹ T⁻²]
- e_a = vapor pressure of overlying air [M L⁻¹ T⁻²]

Evaporation (mass transfer approach)

$$E = K_E v_a \bullet_s - e_a$$

The mass-transfer approach makes direct use of this equation, often written as:

$$E = b_0 + b_1 v_a \mathbf{v}_s - e_a$$

where b0 and b1 are empirical constants that depend chiefly on the height at which wind speed and air vapor pressure are measured. Relations of this form were first formulated by the English chemist John Dalton in 1802 and are often called Dalton-type equations.

Evaporation from a water surface (Penman combination approach) -1

If ground-heat conduction, water-advected energy and change in energy store can be neglected, the energy budget equation becomes:

$$E = \frac{R_n - H}{\rho_w \lambda_v}$$

Eq. 1

where

$$E = evaporation rate [LT1]$$

 R_n = net radiation

 λ_{v} = latent heat of vaporization

- ρ_w = density of water
- **H** = sensible heat transfer

Evaporation from a water surface (Penman combination approach) - 2

The sensible heat transfer flux is given by the following equation:

$$H = \frac{1}{r_{a,H}} \rho_a c_p \left[\mathbf{T}_0 - T_z \right]$$

Eq. 2

where H

 $c_{\rho} T_{0}$

 T_{z}

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

Evaporation from a water surface (Penman combination approach) - 3

The slope of the saturation-vapor-versus-temperature curve at the air temperature can be approximated by:

$$\Delta = \frac{e_s \mathbf{T}_0 - e_s \mathbf{T}_z}{T_0 - T_z} \qquad Eq. 3$$
$$\Rightarrow T_0 - T_z = \frac{e_s \mathbf{T}_0 - e_s \mathbf{T}_z}{\Delta}$$

where

 Δ = gradient of the saturation-vapor-versus temperature curve.

Evaporation from a water surface (Penman combination approach) - 4

Eq (3) can now be substituted into Eq. (2), as follows:

$$H = \frac{1}{r_{a,H}\Delta} \rho_a c_p e_s \P_0 - e_s \P_z$$
 Eq.

And this relation remains true if e_z (the vpd at elevation z) is added and subtracted from each of the terms in bracket:

$$H = \frac{1}{r_{a,H}\Delta} \rho_a c_p \, e_s \, \mathbf{f}_0 = e_z = \frac{1}{r_{a,H}\Delta} \rho_a c_p \, e_s \, \mathbf{f}_z = e_z \qquad Eq. 5$$

Evaporation from a water surface (Penman combination approach) - 5

Since

$$E = K_E v_a \, \mathbf{e}_s - e_z = K_E v_a \, \mathbf{e}_s (T_0) - e_z - Eq. \, 6$$
$$\Rightarrow e_s(T_0) - e_z = \frac{E}{K_E v_a}$$

Then substituting Eq. 6 and Eq. 1 into Eq. 5 yields Eq. 7, which represents the Penman Equation for evaporation

$$E = \frac{R_n + \frac{1}{r_{a,H}\Delta} \rho_a c_p \, \boldsymbol{e}_s(T_z) - \boldsymbol{e}_z)}{\rho_w \lambda_v + \frac{1}{r_{a,H}\Delta} \rho_a c_p \frac{1}{K_E v_a}} \qquad Eq. 2$$

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