GX 2430

OLLSCOIL NA hÉIREANN, GAILLIMH
NATIONAL UNIVERSITY OF IRELAND, GALWAY

(International Postgraduate Hydrology Courses)

M.Sc. (Hydrology)
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PHYSICAL PROCESSES

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Time allowed is ***three*** hours. Attempt any ***five*** questions.

1. *Indicate*, on your answer sheet, legibly and unambiguously, the *symbols* (e. g. (i)-(a), (ii)-(c), etc.) corresponding to the appropriate answers to each of the following *multiple-choice questions* (with *only one* answer to each question):

(i) The *porous block* should be regarded as a matric head sensor rather than a soil moisture content sensor, because:
- (a) its output depends primarily on the moisture content of the block itself which, in turn, is controlled by the matric head of the soil,
- (b) the block is separated from the soil by a semipermeable porous membrane,
- (c) its output depends primarily on the moisture content of the soil which, in turn, is controlled by the matric head of the soil.

(ii) The *unsaturated hydraulic conductivity*, at any matric head, is usually lower than the saturated hydraulic conductivity of the same soil, because:
- (a) of the presence of entrapped air bubbles in the pores of the soil,
- (b) in the unsaturated soil, not all pores are filled with water,
- (c) in the unsaturated soil, water does not move under the influence of gravity.

(iii) The reason why a less permeable layer (a crust) is artificially made on the soil surface when the *unsaturated hydraulic conductivity* is measured by the so-called *crust method* is that:

(a) we can suck water away from the soil through the crust which, in this case, acts as a semipermeable porous plate,

(b) when water infiltrates into the soil through the crust, the hydraulic head loss in the crust is so high that the pressure head at the bottom of the crust becomes negative,

(c) the crust protects the soil surface against the impact of raindrops from a rain simulator.

(iv) The *boundary condition* at the soil surface, for the case of infiltration from rain of variable but low intensity, can be written as:

(a) $\theta = \theta_0 = const.$ for $t \geq 0, \quad z = 0$

(b) $q_z = i_R(t)$ for $t = 0, \quad z > 0$

(c) $q_z = i_R(t)$ for $t \geq 0, \quad z = 0$

where θ is the volumetric moisture content, t is the time, z is the vertical coordinate, q_z is the vertical volumetric flux and i_R is the rainfall intensity.

(v) The *transpiration rate* of a plant canopy is:

(a) the derivative of the root water uptake rate with respect to time,

(b) the integral of the root water uptake rate with respect to time,

(c) the integral of the root water uptake rate with respect to depth.

(vi) If all other factors are kept constant then the *aerodynamic resistance* to water vapour transport above a plant canopy:

(a) will be higher if the wind speed is higher,

(b) will be lower if the roughess of the canopy is higher,

(c) will be higher if the air stratification is more unstable.

(vii) The *actual evapotranspiration rate* of an arbitrary plant canopy is:

(a) always lower than or equal to the corresponding potential evapotranspiration rate for the same canopy under the same weather conditions, except for the case when the canopy surface is wet,

(b) always lower than or equal to the potential evaporation rate from a free water surface under the same weather conditions, except for the case when the canopy surface is wet,

(c) always lower than or equal to the reference crop evapotranspiration under the same weather conditions, except for the case when the canopy surface is wet.

2. *Consider* a paddy rice field flooded with water which slowly infiltrates into the soil at a rate of 5.6 mm/day. The average water depth is 30 cm. The topsoil of thickness 25 cm is saturated and its hydraulic conductivity is 0.35 $m.day^{-1}$. Below the topsoil, there is a layer of dense clayey subsoil 65 cm thick. The pressure head measured at the bottom of the subsoil layer is – 28 cm. The clayey subsoil is underlain by a gravel and sand aquifer in which the groundwater table lies at a depth of 3.55 m below the soil surface. The saturated vertical hydraulic conductivity of the aquifer is $K_s = K_0 = 14.5$ $m.day^{-1}$. The pressure head profile in the upper part of the unsaturated gravel and sand layer is practically vertical, i.e., water percolates downwards through it driven only by gravity.

Assuming that the hydraulic conductivity of the clayey subsoil is constant (i.e., independent of the pressure head), while the vertical hydraulic conductivity K of the gravel and sand layer obeys the Gardner exponential formula:

$$K = K_0 \exp(\alpha h_p)$$

for all negative pressure heads, *estimate* the hydraulic conductivity of the subsoil and the Gardner parameter α for the gravel and sand layer. *Round* your final results to *two* significant digits.

3. *Estimate* the time of incipient ponding during a rainfall of constant intensity $i_R = 0.88$ $mm.min^{-1}$ for a soil characterised by its saturation hydraulic conductivity $K_s = 0.26$ $mm.min^{-1}$ and by its sorptivity $S = 14.3$ $mm.min^{-1/2}$ (at a given initial moisture content). *Use* the time compression method, *assuming* that the instantaneous ponding infiltration curve can be approximated by the Philip two-term infiltration equation. *Take* Philip's parameter A as one half of the saturated hydraulic conductivity K_s. *Round* you final result to *two* significant digits.

4. *Estimate* the average evapotranspiration rate for a relatively homogeneous catchment for which it is known that vegetation is always sufficiently supplied with water, during a week over which the average weather elements were as follows:

Net radiation:	$R_n = 87.6$ $W.m^{-2}$
Soil heat flux (positive downwards):	$G = -15.2$ $W.m^{-2}$
Air temperature:	$T = 12.7$ °C
Relative humidity:	$RH = 85$ %
Wind speed at 2 m elevation:	$u = 2.64$ $m.s^{-1}$

Use the Priestley-Taylor formula with the standard value of the coefficient α (1.26). *Take* the following values of physical parameters:

Psychrometric constant:	$\gamma = 65.6$ $Pa.K^{-1}$
Water density:	$\rho_w = 1000$ $kg.m^{-3}$
Latent heat of vaporisation:	$\lambda = 2\,462\,000$ $J.kg^{-1}$

Decide which of the input data you need. *Use* the semi-empirical exponential formula for calculating the saturated vapour pressure and its derivative with respect to time. *Round* your final result to *three* significant digits.

5. *Assuming* that the air stratification is approximately neutral, estimate the canopy resistance r_c for an alfalfa field, on a cloudy and windy summer day, if the following data are available:

Net radiation:	$R_n = 205$ W.m^{-2}
Soil heat flux:	$G = 0$ (is negligible)
Bowen ratio:	$\beta = C/(\lambda F) = 0.375$

where C is the sensible heat flux and λF is the latent heat flux (both taken as positive upwards).

Friction velocity (from the wind speed profile):	$u_* = 0.396$ m.s^{-1}
Zero plane displacement:	$d = 52$ cm
Roughness length:	6.2 cm
Vapour pressure at 2 m elevation:	$e = 1.833$ kPa
Air temperature at 2 m elevation:	$T = 21.7$ °C

Assume the following values of the physical parameters:

Air density:	$\rho_a = 1.197$ kg.m^{-3}
Specific heat of air at constant pressure:	$c_p = 1010$ J.kg^{-1}.K^{-1}
Psychrometric constant:	$\gamma = 66.3$ Pa.K^{-1}
Latent heat of vaporisation:	$\lambda = 2\,440\,000$ J.kg^{-1}
Water density:	$\rho_w = 1000$ kg.m^{-3}
von Karman constant:	k = 0.41

Use the semi-empirical exponential formula for calculating the saturated vapour pressure. *Do not use* the Penman-Monteith equation. *Round* your final result to *three* significant digits.

6. *Explore* the attached graph, taken from Kutilek, M., and Nielsen D. R., 1994: Soil hydrology. Catena Verlag, Cremlingen-Destedt, p. 226. The graph presents the results of measurements made at the depth 1.8 m below the soil surface. The "4-cm irrigation" regime consisted of applying 4 cm of water every week. The "cumulative water loss relates to the whole soil profile between the surface and the depth 1.8 m. *Explain* which quantities are plotted on the axes, which curve relates to which quantity and what the figures ascribed to some of the data points mean. *Determine* in which direction (upward or downward) the soil water is flowing at different time instants.

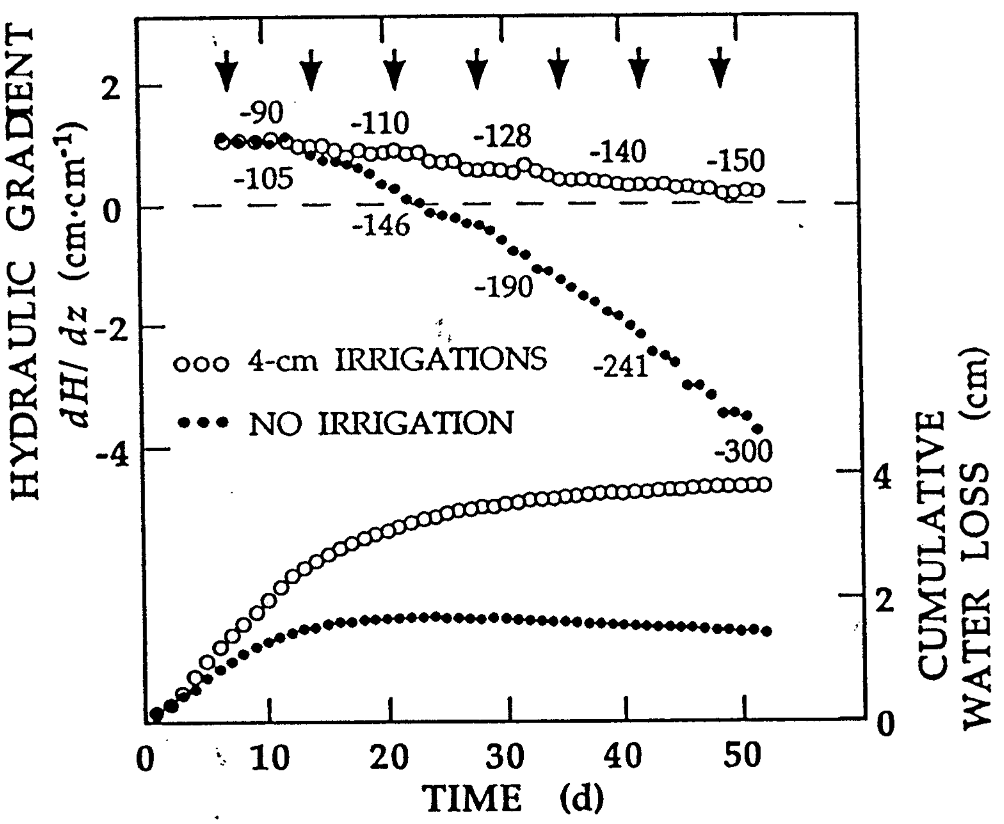

Figure 7.2. Hydraulic gradient, soil water pressure head and cumulative water lost from a 1.8-m soil profile cropped to ryegrass during the summer without any rainfall under two irrigation regimes (LaRue et al., 1968).

7. *Explore* the attached figure, taken from Akhtar, M. E., and Niyami, M. I. (eds.): Soil physics – Application under stress environments. Proc. Int. Symp., 22-26 January 1898, Islamabad. Pakistan Agricultural Research Council, Islamabad, p. 123. *Explain* which quantitites are plotted on the axes. *Explain* also the intended purpose of the indicated measurements and calculations. *Discuss* whether or not, in the situation depicted, we could estimate the hydraulic conductivity of the soil using the instantaneous profile method.

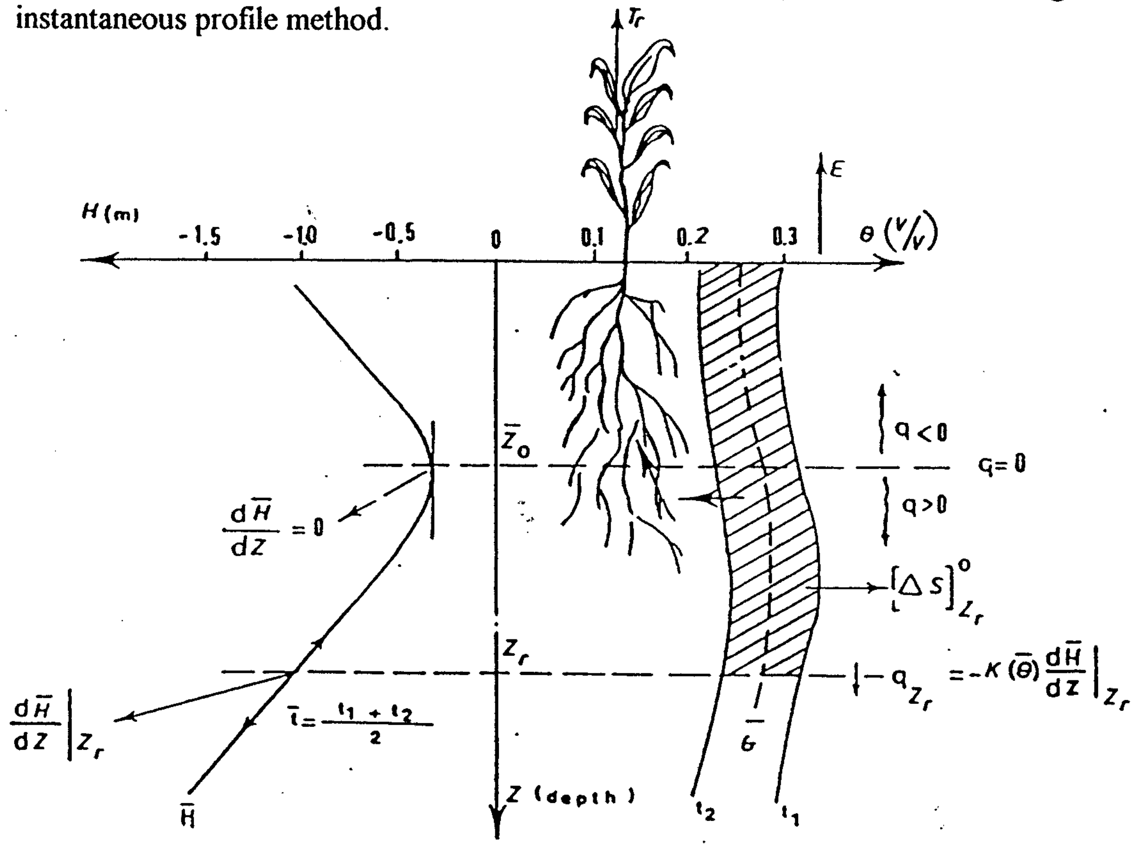

Figure 10. Diagram illustrating the calculation of the crop evapotranspiration when the zero flux plane is located within the root zone.

2.2. Cropped soil

The calculation procedure for the evapotranspiration will depend on whether the zero flux plane is located above or below the rooting depth:

a. if the rooting depth does not extend below the zero flux plane, the calculation procedure for ET_{cr} and the drainage component is similar as the one for a bare soil (Figure 9).

b. if the rooting depth is extended below the zero flux plane the evapotranspiration and the drainage component can only be calculated using Darcy's equation whereby the depth z_r is taken below the rooting depth (Figure 10).

The drainage at depth z_r is given by:

$$q_{z_r} = -K(\bar{\theta})\frac{\overline{dH}}{dz}\Big|_{z_r}$$

and the evapotranspiration by:

$$ET_{cr} = P + I - [\Delta S]^{o}_{z_r} - q_{z_r}\Delta t - R$$

It is possible that more than one zero flux plane occurs in the soil profile, e.g. in case of successive wet and dry periods. In such a case one has to take the deepest zero flux plane into consideration for the calculation of ET_{cr} and q_{z_r}.