Measuring evaporation from soil surfaces for environmental and geotechnical purposes

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Abstract

There are many reasons for the need to assess rates and quantities of evaporation or evapotranspiration from natural soil surfaces, the surfaces of deposits of mine or industrial waste, or soil-covered waste surfaces. These include assessing water balances for near-surface soil strata, landfills, tailings dams and waste dumps and suitable deposition or application intervals for hydraulic fill tailings dams, or for the disposal of liquid wastes on land. The surface energy balance is probably the most widely used method for assessing evaporation, although other methods are also available. The surface energy balance method is studied in this paper.

The surface energy balance is by no means a new method (it was proposed by Bowen in 1926), but appears to be almost unknown to civil engineers, and in particular to those engaged in geotechnical engineering or waste management. The aim of this paper is to draw attention to this useful technique and to show how it can be applied in many aspects of environmental geotechnics and waste management.

The paper describes the measurements made to assess the surface energy balance as well as its analysis, and presents the results of typical measurements. It also presents numerical values of the parameters and constants needed for the analysis. The experimental difficulties of the analysis are described and examined, and the method's accuracy is assessed by means of laboratory and field measurements. The paper is intended to be both informative and a practical guide to measuring evaporation in the field.

List of terminology

(In order of introduction into text, but excluding standard SI units)

h	=	hour
d	=	day
r	=	relative humidity
$\bar{r}$	=	average relative humidity
T	=	temperature
$\bar{T}$	=	average temperature
R_A	=	solar radiation received at outer limit of atmosphere
S_o	=	solar constant
α	=	planetary albedo
ϕ	=	latitude
δ	=	sun's declination
R_i	=	incoming solar radiation at Earth's surface
C	=	atmospheric clarity
R_n	=	net solar radiation received at earth's surface
a	=	albedo of ground surface
G	=	soil or waste heat flux
H	=	sensible heat flux
L_e	=	latent heat flux for evaporation
W_E	=	wind energy flux
E_W	=	evaporation caused by wind
Δ	=	slope of saturated water vapour pressure vs. temperature curve
γ	=	constant in wet-dry bulb psychrometer equation
u	=	mean wind speed
n/D	=	ratio of actual to potential hours of sunshine
ΣG, ΣH, ΣL_e, ΣR_n, etc.	=	heat or energy fluxes integrated over time
ρ_a	=	density of air
C_a	=	specific heat of air
k_h	=	eddy diffusivity for heat in air
$\delta T/\delta z$	=	temperature gradient with height above ground surface
E	=	evaporation or vapour flux
k_v	=	eddy diffusivity for vapour in air
$\delta\rho_v/\delta z$	=	vapour density gradient with height above ground surface
λ	=	latent heat of vaporization for water (2470 $kJ\cdot kg^{-1}$)
E	=	ratio of molecular masses of water and dry air
$\delta e/\delta z$	=	vapour pressure gradient with height above ground surface
P	=	atmospheric pressure
ß	=	Bowen's ratio
z_a	=	height of air affecting evaporation at ground surface
$(\Delta\bar{T}_a)$	=	average change of air temperature over height z_a
$[h]_{z_S}^{z_R}$	=	transfer coefficient for heat between surface level(z_S) and a reference level (z_R)
t	=	time interval
$T(z_S)$, $T(z_R)$	=	temperatures at z_S and z_R respectively
T_1, T_2	=	air temperatures at levels 1 and 2
e_{sat}	=	saturated water vapour pressure at mean of T_1 and T_2
r	=	relative humidity. r_1, r_2 = relative humidities at levels 1 and 2
Δ	=	slope of e_{sat} versus T curve
γ	=	.057kPa.°C^{-1} = constant in equation (6a)
u_1, u_2	=	wind velocities
z_1, z_2	=	heights above ground surface
z_G	=	depth of soil or waste heated diurnally
$(\Delta\bar{T})$	=	average change of temperature over depth z_G
C_G	=	specific heat of soil or waste
ρ_G	=	bulk density of soil or waste
G_{Gd}	=	specific heat of dry soil or waste
C_w	=	specific heat of water (4.19 $kJ\cdot kg^{-1}\cdot °C^{-1}$)
w	=	gravimetric water content of soil

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