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NOTE

CALIBRATION OF SOIL HEAT AND WATER FLUX METERS

J. W. CARY

Snake River Conservation Research Center, Kimberly, Idaho[1]

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Philip (3) applied the theory of heat flow in a heterogeneous system to the design of soil heat flux meters. Soil water flux meters operate on similar principles and have been studied by Cary (1, 2). Both the heat and water flux meters must be precalibrated. The calibration depends upon the conductivity of the soil, and so the variability of soil heat and water conductivity becomes one of the main problems in practical field use of the instruments. The purpose of this note is to point out that the dependence on soil conductivity can be eliminated by using two meters simultaneously.

Philip (3) began his analysis of the heat flux meter with the exact solution for heat flux through an oblate spheroid. This relation is

$$\frac{J}{q} = \frac{\epsilon}{1 + H(\epsilon - 1)} \tag{1}$$

where J is the flux through an oblate spheroid which has a uniform conductivity, K_t, q is the heat flux through the surrounding media with a uniform conductivity K_s, ϵ is K_t/K_s, and H is a constant dependent only on the dimensions of the oblate spheroid. Philip believed that this relation could be used as a close approximation for heat flux transducers in soil and that H would remain very nearly independent of fluxes and conductivities. The use of equation (*1*) to describe the operation of either heat or water flow meters in soil assumes a homogeneous soil conductivity, K_s, transporting a uniform flux, q, at the boundaries of the zone of influence of the meter. In general, the flow meters are designed to be unidirectional; thus it is further assumed that q may be taken as the vector component of total flux in practical field situations.

For measuring unsaturated soil water flow, a cylinder around the flow sensing unit has been shown to have advantages. The average conductivity of such a soil water flow meter, K_t, was given by Cary (2) as

$$K_t = \frac{bKK_s}{cK + aK_s} \tag{2}$$

where K is the fixed conductivity of the sensing unit in the meter, a is the thickness of this unit, c is the length of soil enclosed in the cylinder around the unit, and b is the overall length of the meter (fig. 1). Equation (*2*) assumes that all of the soil in the immediate vicinity of the flow meter, including that enclosed in the cylinders on each end, may be satisfactorily represented by an average conductivity, K_s. In cases where a cylinder and the enclosed soil is not used as part of the transducer, $K_t = K$ which is constant.

Using equation (*2*) to replace ϵ in equation 1, and solving for q gives

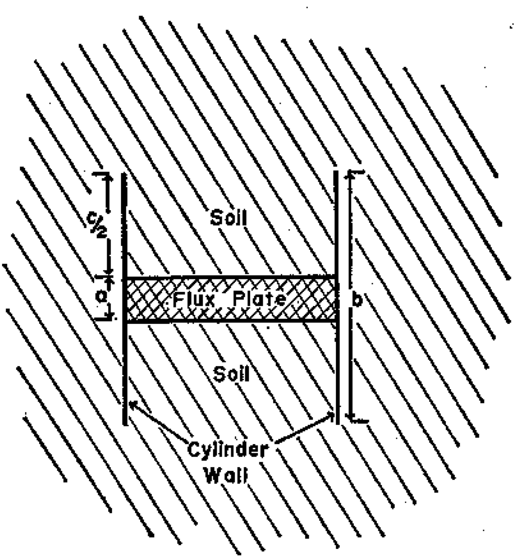

FIG. 1. Diagram of a cross section of a water flux transducer installed in the soil.

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$$q = \frac{J}{bK}(K_s\gamma + K\sigma) \qquad (3)$$

where $\gamma = a - Ha$, and $\sigma = c + Hb - Hc$.

Suppose now that a second water flow transducer is placed in the soil just outside the zone of influence of the first transducer, but under conditions that are otherwise identical. Let this second transducer have the same dimensions and construction as the first, except that the fixed conductivity in the sensing unit be different (represented by k), which will cause the flux through the second transducer to also be different (represented by j).[2] Equation (3) written for the second transducer then becomes

$$q = \frac{j}{bk}(K_s\gamma + k\sigma). \qquad (4)$$

Solving equation (3) for K_s, putting the result into equation (4), and solving for q gives

$$q = Aj\left(\frac{n-1}{n-m}\right) \qquad (5)$$

[2] It may be possible to design water flow transducers so that two units are not needed. If an impermeable barrier were placed between two porous plates in the center of the transducer and the flux into one plate routed to the surface through a flow meter and back into the other plate, a known flow resistance could be placed in series with the flow at the surface. Alternately using and bypassing this extra resistance would accomplish the same end as two flow meters, provided the measurements could be made before a significant change in flux occurred.

where A is σ/b, m is j/J, and n is k/K. The constant A should depend only on the meter shape and geometry. The value of n is constant and known, while j and m are quantities measured by the two meters. Consequently, the pair of meters need to be calibrated only once to find the value of A. Supposedly, this could be done in any soil at any moisture content for any one known steady state flow situation. Two meters and equation (5) should then give one vector of the real soil water flux, q, in any soil under any conditions so long as the moisture potential does not move out of the tensiometer range and the other assumptions previously stated are not grossly violated. If standard heat flux transducers or the type of water flux meter originally studied by Cary (1) are used (i.e., $K_s = K$), the result is identical to that given in equation (5) except that $A = H$.

Some of the approximations required in applying equations (1) and (2) to the operation of transducers in the soil may result in the failure of equation (5) to be exact, but it should prove useful in the design and development of soil heat and water flow transducer systems.

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