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Estimation of Water Flux in Variably Saturated Soil with a Penta-Needle Heat Pulse Probe

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The penta-needle heat pulse probe (PHPP) employs a central heater needle surrounded by an orthogonal arrangement of four thermistor needles. By inversely fitting an analytical solution for two-dimensional heat transport with an infinite line source, both components of the flux in a plane normal to the axis of the PHPP needles, Jx and Jy, thermal conductivity, and thermal diffusivity can be estimated. Using estimated Jx and Jy, water flux magnitude and direction can also be calculated. In this study, the applicability of PHPP estimations was tested in both of saturated and unsaturated water flows in sand. Laboratory column experiments under steady-state saturated (flux range of 180-430 cm/d) and unsaturated (1.9-130 cm/d) water flow conditions were conducted. Two PHPPs were installed with orientations to yield water flow directions of 30^o and 45^o. In case of saturated flow condition, estimated Jx and Jy agreed well with measured water fluxes (less than 25 % relative errors), resulting in good estimations of water flow magnitudes and directions. In case of unsaturated flow condition, water fluxes estimated by PHPP with 30^o agreed well with measured flux. However, one component (Jx) from PHPP with 45^o showed a constant discrepancy (-55 cm/d) in any flow rates. This result indicates that differences of constant resistance between sand and needle, heterogeneity of the sand-water-air system, and heterogeneity of microscopic unsaturated flow in measurement area resulting from water content changes (0.38 cm^3/cm^3 for saturated flow to 0.10 cm^3/cm^3 for unsaturated flow) affect PHPP estimations.