WATER RESOURCES RESEARCH, VOL. 23, NO. 8, PAGE 1704, AUGUST 1987

Reply

F. STAGNITTI

Mathematics Department, Warrnambool Institute for Advanced Education, Warrnambool, Victoria, Australia

M. B. PARLANGE, T. S. STEENHUIS, AND J.-Y. PARLANGE

Department of Agricultural Engineering, Cornell University, Ithaca, New York

We appreciate the comment by *Hurley and Pantelis* [this issue] and the opportunity to clarify our remarks on their work made in our paper [*Stagnitti et al.*, 1986]. Our paper recognized that the work of *Hurley and Pantelis* [1985] "justified and expanded" our work.

Hurley and Pantelis [1985] developed a general kinematic model describing downslope flow in the saturated and unsaturated zone. Their theory "justified" the simplification of Richards' equation for thin soil layers, as we acknowledged in our paper [*Stagnitti et al.*, 1986, p. 632]. We stated that "soil water diffusion tends to maintain a uniform water content within the layer" [*Stagnitti et al.*, 1986, p. 631], whereas they find more precisely that the total "head is ... approximately constant along normals to the surface" [*Hurley and Pantelis*, this issue]. We were mistaken when we stated that this implied that the water content was also constant along the normals to the hillslope, as correctly pointed out by *Hurley and Pantelis* [this issue]. However, the difference between our assertions and theirs does not affect the calculation of the drainage to any significant extent for thin layers.

Their model also "expanded" ours by applying the method of characteristics to a soil layer which does not have a "uniform soil layer thickness" and "constant slope angle" [*Hurley and Pantelis*, this issue]. However, since our principal aim was to obtain a fully analytical solution, some geometrical limitations are necessary. Once analytical solutions are obtained, they can be applied to simple experiments, as we did with the Coweeta data [*Hewlett and Hibbert*, 1963], or used to validate numerical models, which then can be applied to more complex situations with confidence.

More importantly, Hurley and Pantelis do not agree with our main and in fact only criticism that their "model ignores capillary effects, since such effects are included in Richards' equation" [*Hurley and Pantelis*, this issue]. We still believe that our criticism is valid and fundamental. For this reason, we shall elaborate more carefully.

Hurley and Pantelis' [this issue] argument that their model deals with capillarity because Richards' equation does would be convincing if their simplification of Richards' equation was always valid. In reality, this may not be so. For example, a difficulty with their model may result from no specification of boundary conditions at the foot slope of the hill. Certain conditions may well be incompatible with the condition of constant total head perpendicular to the hillslope. *Hurley and Pantelis*' [1985] model would hold in general, that is, independent of the boundary conditions at the bottom of the hill, only if such conditions affected the water balance for a short distance upslope. In that case, the amount of water associated with conditions at the foot of the slope would be negligible in comparison with the amount of water for the entire hillslope. Clearly, the effect of dropping these conditions is related to neglecting higher derivatives introduced by capillarity in the transport equation.

Thus *Hurley and Pantelis*' [1985] model requires more than "only two assumptions: (1) that Richards' equation is obeyed and (2) that the thickness of the soil layer is small in comparison with a typical hillslope dimension" *Hurley and Pantelis* [this issue]. It also requires that the typical hillslope dimension be much greater than the dimension along the hill affected by capillarity. Mathematically, the difficulty arises because of the implicit assumption they make that the variation of the pressure head is at most of the order of the thickness of the soil layer. Since the thickness of the soil layer is much smaller than the length of the hillslope, it results that capillary forces are automatically ignored in their model.

Our model recognizes this limitation, and an allowance for capillarity is made. For the Coweeta data, capillary rise affected a significant portion of the hillslope. If we had ignored this effect, then the predicted drainage would have been more than 50% larger than was actually observed.

In conclusion, then, models using the method of characteristics, like the one developed by *Hurley and Pantelis* [1985] and ours [*Stagnitti et al.*, 1986], are extremely useful to analyze water movement in thin layers. However, care must be taken to estimate capillary effects introduced by boundary conditions at the bottom of the hill to ensure that they are negligible or to introduce a correction in the model to account for them if necessary, as we did.

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J.-Y. Parlange, M. B. Parlange, and T. S. Steenhuis, Department of Agricultural Engineering, Cornell University, Ithaca, NY 14853.

F. Stagnitti, Mathematics Department, Warrnambool Institute for Advanced Education, P. O. Box 423, Warrnambool, Victoria 3280, Australia.

(Received April 10, 1987;
accepted May 18, 1987.)

Paper number 7W4928.
0043-1397/87/007W-4928$02.00