# Modelling IP3 Watersheds: Determining Retained Soil Moisture Using Both Field Capacity and Topography

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## INTRODUCTION

*Soil drainage processes is often represented using a series of sloping soil layers that are subject to infiltration, percolation, and downslope interflow. To be successful, such an approach requires a means to calculate the distribution of retained water in the sloping soil horizons as a function of time.* Traditionally soil moisture is represented by conceptually sound but somewhat arbitrary functions. For example, retained water was first unconstrained in WATDRAIN, the soil moisture module in MESH. Then, in WATDRAIN2, field capacity was used as a limit, defined as the water remaining in the soil when suction is at one third atmosphere. In both cases the model had difficulty in dry conditions. A new approach is proposed for near surface flow that includes an approximate solution to Richard's Equation for a sloped aquifer for both saturated and unsaturated conditions, as well as a definition of field capacity based on soil properties and topography. The results for field capacity are compared with the original data sets used to determine the one third atmosphere definition. The impact of this revised approach on simulation results is demonstrated.

## BACKGROUND

*The method is based on two asymptotic end states: saturated gravity dominated flow and unsaturated suction dominated flow.* The soil horizon experiences three states: an initial state, in which the aquifer is fully saturated; a transition state, in which the aquifer is partially saturated; and a steady state, in which the aquifer water content equals its field capacity. The concept is shown in figure 1).

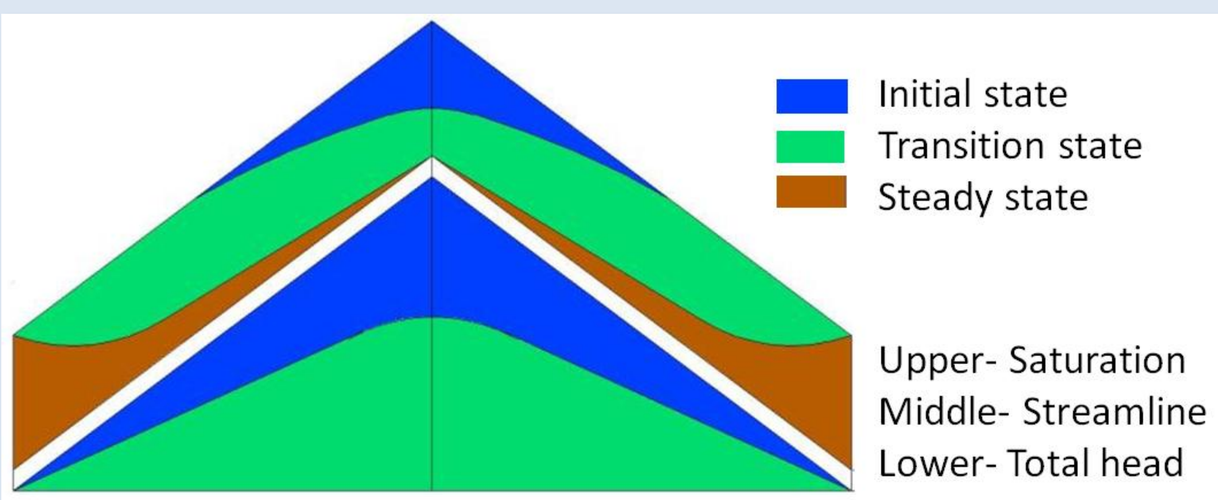


**Figure 1) Developing concept (top diagram-saturation in hillslope, bottom triangular diagram-matric potential)**

A consistent soil moisture parameterization scheme was found for shallow aquifers by solving a modified Richards Equation analytically. An analytical solution for purely gravity dominated flow is given by

$$s = min\left[1, \left(\frac{\theta_s}{ck_s\Lambda}\cdot\frac{x}{t}\right)^{\frac{1}{c-1}}\right]$$

where s is the saturation, $\theta_s$ is the porosity, $\Lambda$ is the slope, c is the Brook-Corey soil index, x is the axis along the slope, $k_s$ is the saturated hydraulic conductivity, t denotes time, and x is the downslope distance.

## BACKGROUND(Cont.)

For the uphill zone, the total head gradient is assumed negligible, providing the following solution for suction dominated flow.

$$s = \left[1 - \frac{\Lambda(x - x_f)}{\psi_f}\right]^{-\frac{1}{b}}$$

Where $\psi_f$ is the suction head at the interface between solutions (i.e., at $x_f$) and b is a soil property index.

## BULK FIELD CAPACITY CALCULATION

*Combining the gravity dominated flow and suction dominated flow and integrating the solution along the hillslope, a useful operational definition of bulk field capacity ($\bar{\theta}_{fc}$) is obtained.*

$$\bar{\theta}_{fc} = \frac{\theta_s}{b-1}\left(-\frac{\psi_a b}{L\Lambda}\right)^{\frac{1}{b}}\left[(3b+2)^{\frac{b-1}{b}} - (2b+2)^{\frac{b-1}{b}}\right] \qquad (1)$$

*Note that L is the total downslope length, $\psi_a$ is the air entry pressure.*

Figure 4 demonstrates that *the definition of equation (1) is consistent with the existing operational definition of field capacity for non-sloping soils, but further incorporates an dependency upon the air entry pressure of the soil and is extendible to lateral flow calculations. The concept of bulk field capacity is shown to be dependent upon sample length, clarifying some discrepancies between reported field capacities from the literature. To compare with published data, $\Lambda$ is set to equal 1.*

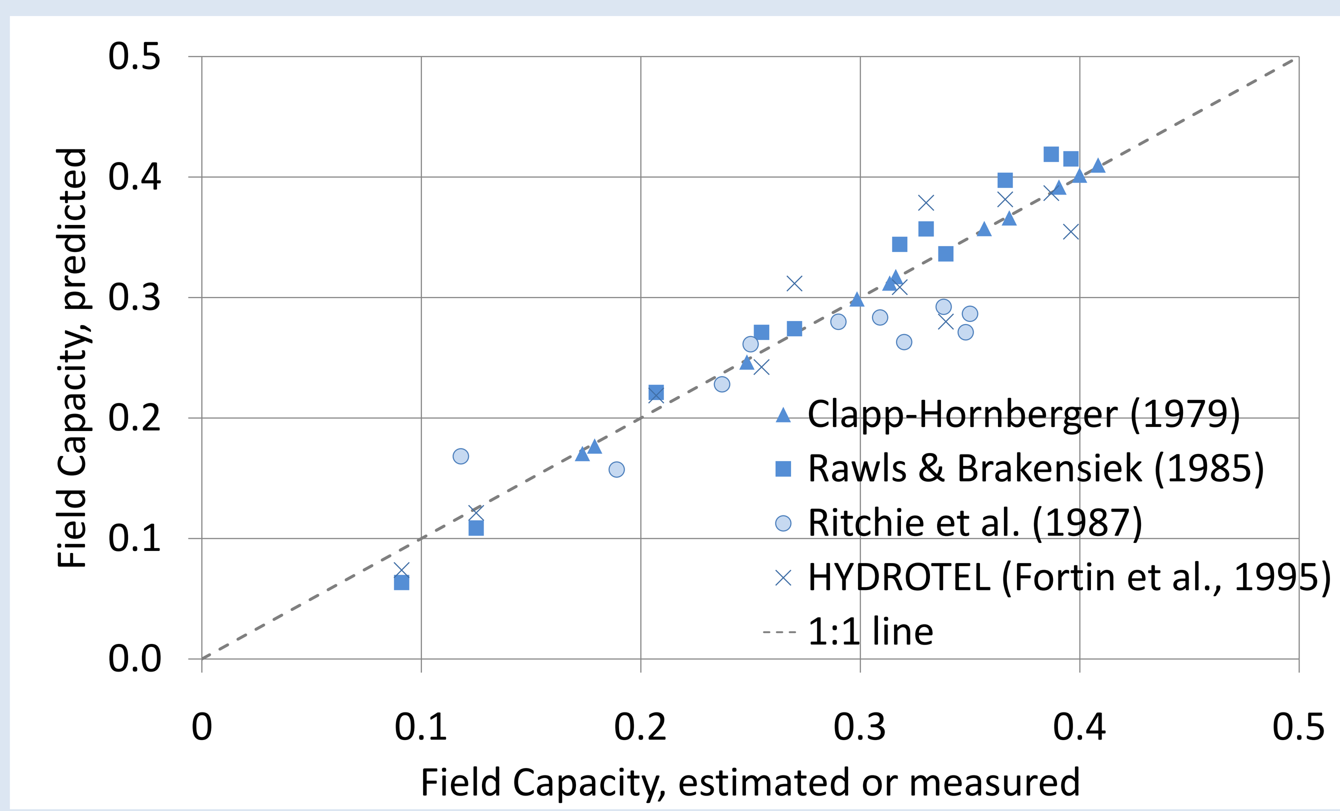


**Figure 4) Comparison of the operational definition of field capacity to measured and estimated field capacities of vertical soil columns (Each data point represents a group of soils under one textural class)**

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## VERIFICATION BY NUMERICAL METHOD

The soil parameters used here are consistent to sandy clay loam (Dingman, 2002). Under identical system geometry and hydraulic conductivity distributions, a one-dimensional Richards' equation is solved by using a fully implicit Crank-Nicolson finite difference scheme. The comparisons between analytical (AS) and numerical (NS) solutions are shown in figure 2, for gravity-dominated case, and figure 3, for suction-dominated case.

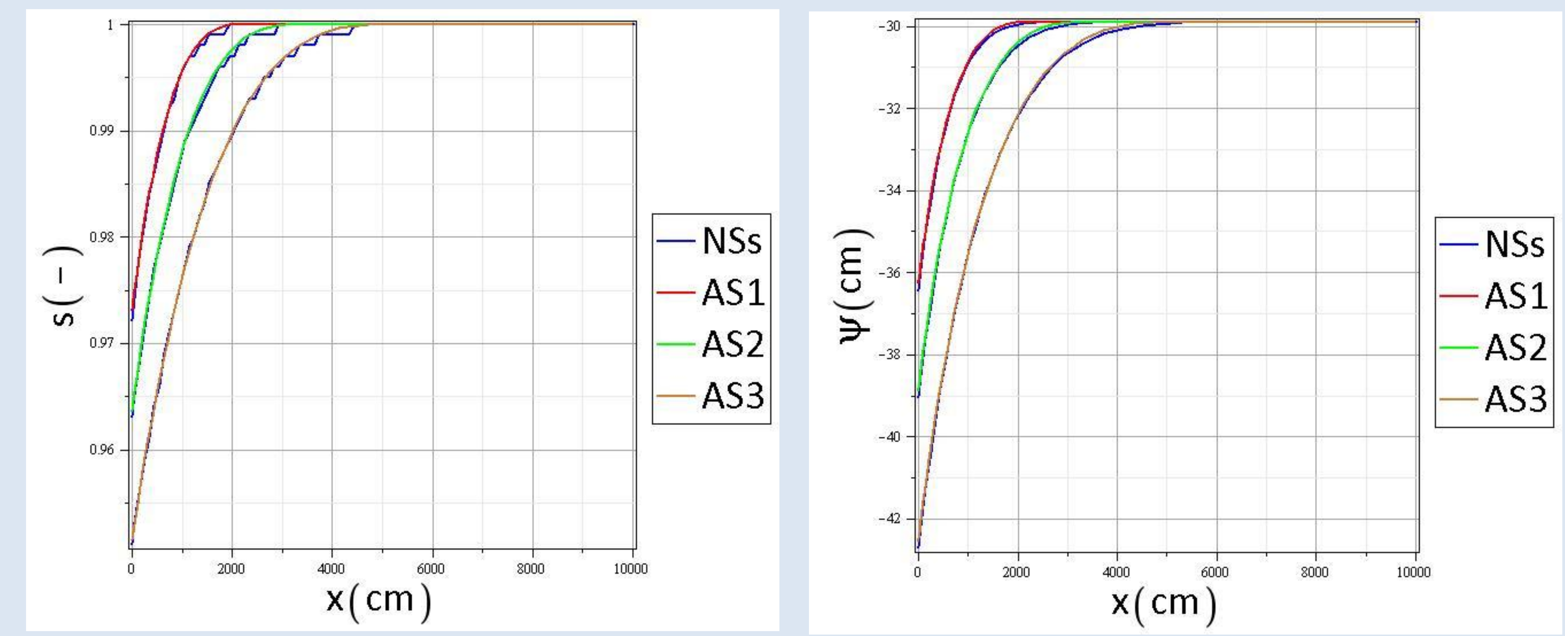


**Figure 2) Gravity dominated flow (from top: at t=2.0e6s, 4.0e6s, and t=8.0e6s)**

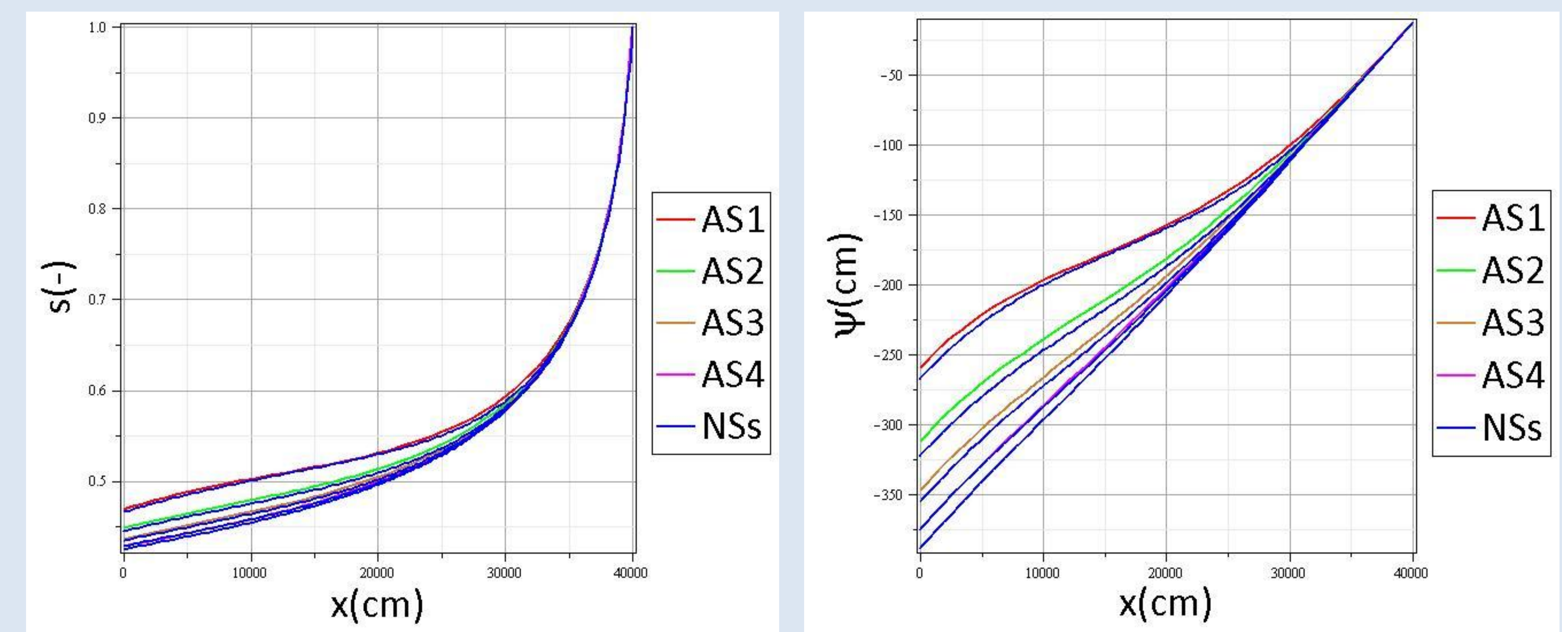


**Figure 3) Suction dominated flow (from top: at t=4e4d, 8e4d, 1.2e5d, and t=1.6e5d)**

Figure 2 shows that *the analytical solution matches the numerical solution in detail for wet soil.* Figure 3 shows that *although the analytical solution tends to either underestimate or overestimate the numerical solution, it matches on average overall.*

## CONCLUSION

*The proposed soil drainage solution matches numerical solution in detail for wet soil and on average for dry soil. The model accurately predicts field capacity and incorporates topography parameters.*

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