ICIWRM – 2000, Proceedings of International Conference on Integrated Water Resources Management for Sustainable Development, 19 – 21 December, 2000, New Delhi, India

Simulation of soil moisture movement in a forested watershed

B. K. PURANDARA and C. P. KUMAR
Hard Rock Regional Centre, National Institute of Hydrology, Belgaum - 590 001 (Karnataka), India

Abstract
Prediction of soil moisture retention and movement is very important for irrigation scheduling, crop planning, runoff estimation and drought monitoring. Application of numerical techniques provides estimates for different hydrologic variables including soil moisture. Soil moisture in the root zone is best predicted by the simulation models which consider withdrawal of water from the root zone. The changes in soil water content is predicted generally by one-dimensional continuity equation coupled with volumetric root sink term. The present study has been carried out to simulate soil moisture, evapotranspiration, runoff and drainage in Barchi forested watershed. Hydrologic parameters such as infiltration, hydraulic conductivity and soil moisture retention characteristics under different types of forest covers were determined by using Disc Permeameter and Guelph Permeameters and pressure plate apparatus. A simulation model, SWIM (Soil Water Infiltration and Movement) developed by CSIRO, division of Soils, Australia) was applied. It deals with the numerical solution of one-dimensional Richard's equation based on the assumption that the soil column may be vertically inhomogeneous and horizontally uniform. Predicted soil moisture profiles for post-monsoon and pre-monsoon period closely follow the trend of observed moisture profile in the watershed. Runoff, evaporation and drainage were also estimated. The results are quite comparable with earlier studies.

INTRODUCTION

Hydrological processes involving soil-water interactions in the field, and particularly, the flow of water in the rooting zone of most crop plants, occur while the soil is in unsaturated condition. The ability of the soil to absorb, retain and transmit water gives rise to the notion of this zone behaving as a leaky reservoir. The water movements in the unsaturated zone, together with the water holding capacity of this zone, are very important for the water demand of the vegetation, as well as for the recharge of groundwater storage (Lakshman, 1993). A fair description of the flow in the unsaturated zone is crucial for predictions of the movement of pollutants into groundwater aquifers. Input at the soil surface is in the form of precipitation or irrigation out of which a part is absorbed and the other runs off. The water that infiltrates into the soil is later partitioned between that amount which returns to the atmosphere by evapotranspiration and which seeps downward and recharges the saturated zone. Soil Physicists, in the recent years have offered analytical solutions for describing water movement in the unsaturated zone and validated through several laboratory experiments. However, the natural conditions existing in the field soils are in no way comparable to the idealised and controlled laboratory conditions. Therefore, it is necessary to apply mathematical models to simulate the soil moisture profiles under field conditions.

Water in the rooted part of soil is quite mobile. Its distribution over time and depth is important because it determines the amount of water available to the crop. Water enters the soil as rain or irrigation water and also by capillary rise from the groundwater table. It leaves the soil by evaporation, drainage, and is taken up by roots for their transpiration needs. Gravity and gradients in moisture suction cause water movement within the soil. Soil physical characteristics (e.g. hydraulic conductivity) codetermine rate of water flow.

A soil profile generally consists of different layers with distinct physical characteristics and root activity. The thickness and physical characteristics of each layer must be specified for soil moisture simulations. The mathematical equations describing the soil processes are the same for all layers, but the outcome is specific to each layer in view of varying parameter values.

Spatial variability of the soil water content at a given depth in the field is caused by spatial heterogeneity of physical characteristics of soil layers, irregularities at the surface, artificial drainage structures and by heterogeneous root distribution. This spatial variability is difficult to include in the models.

One of the predominant factors which can affect the movement of soil moisture in the unsaturated zone is the type of land use cover such as forest, grass, agriculture, barren land etc. Different land uses may have different effects on movement of the water through unsaturated zone. Forest soils are noted for the proliferation of macropores, especially in the surface layers, because of the high density of roots and soil fauna activity. Such macropores allow the vertical by-passing of the unsaturated matrix and allow preferential flow of water to reach the saturation zone more quickly than the soil matrix.

The present study has been carried out to simulate the soil moisture movement and estimate the evapotranspiration, runoff and deep percolation in small forested watershed (Barchi) of Karnataka (India) using the SWIM model.

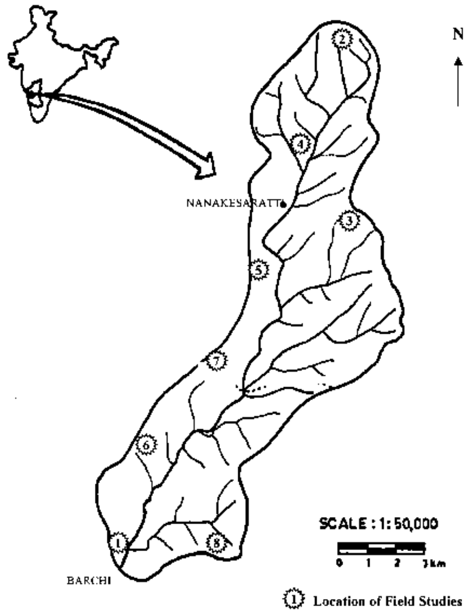
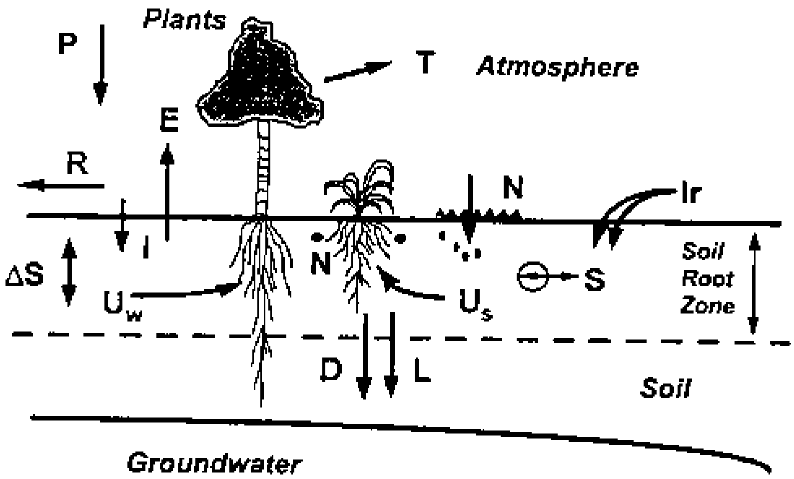


Figure 1. Location of Barchi watershed.

STUDY AREA

The Barchi river originates from Thavaragatti in Western Ghat at an altitude of about 734 m, and 20 km north of Dandeli in Uttara Kannada district of Karnataka State. The watershed is relatively short in width and the river flows in a southerly direction and joins the Kali river near Dandeli. The total watershed area is around 14.5 sq.km. The watershed lies between 75^{o} 35' E and 75^{o}40' E longitude and between 13^{o}18'and 15^{o}24' latitude (Figure 1). High land region, forming part of the foot hills of western ghats consists of steep hills and valleys intercepted with thick vegetation. The slopes of the ghats are covered with dense deciduous forest. Most of the trees looses their leaves during the latter part of the summer months. Barchi watershed has distinct seasons in the year, such as winter, summer and monsoon. The principal soil found in the watershed are silty clay and red gravelly soil. The watershed receives the rainfall during the south-west monsoon period, the average rainfall being around 1500 mm. The average annual evaporation in the watershed is around 1300 mm.



P= Percipitation, R= Runoff, I= Infiltration, U_w = Water uptake, U_s = Solute uptake, T= Transpiration, E = Evaporation, D= Drainage, L= Solute leaching, I_r = Irrigation/ fertigation, N= Nutrients/fertiliser, ΔS = Storage, S= Solute source/sink.

Figure 2. Components of the soil water and solute balances addressed by SWIMv2.1.

SOIL WATER INFILTRATION MODEL (SWIM)

SWIM is an acronym that stands for Soil Water Infiltration and Movement. It is a software package developed within the CSIRO Division of soils for simulating infiltration, evapotranspiration, and redistribution. The model is based on a numerical solution of the Richards' equation and the advection-dispersion equation. It can be used to simulate runoff, infiltration, redistribution, solute transport and redistribution of solutes, plant uptake and transpiration, soil evaporation, deep drainage and leaching. The physical system and the associated flows addressed by the model are shown schematically in Figure 2. Soil water and solute transport properties, initial conditions, and time dependent boundary conditions (e.g., precipitation, evaporative demand, solute input) need to be supplied by the user in order to run the model. The governing partial differential equation (Richards' equation) applicable for one-dimensional flow in the unsaturated zone can be written as:

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x} K \left[\frac{\partial \psi}{\partial x} + \frac{dz}{dx} \right] + S \qquad (1)$$

where, θ = volumetric water content [cm3/cm3]

t = time [h]

x = distance into the soil[cm soil];

K = hydraulic conductivity[cm2 water/cm soil/h]

ψ = matric potential [cm water];

z = gravitational potential[cm];and

S = sink strength[cm3 water/cm3 soil/h]

The model deals with a one-dimensional soil profile. For a vertical soil profile, this means that it may be vertically inhomogeneous, but must be horizontally uniform. This assumption has two consequences of importance in many common simulations. There is only one hydraulic conductivity function for each layer, so that any macropore, or bypass flow can only accounted for in a limited way. Secondly, the calculated solute concentrations apply to the whole soil layer, which means that there is no concentration gradient from the bulk soil to near the root surface. The presence of such a concentration gradient may in reality affect the soil osmotic potential and hence water and solute uptake (Verburg, et al, 1996).

SIMULATION OF SOIL MOISTURE MOVEMENT

Input Data

Rainfall: Based upon the available information, two distinct soil layers were identified. The following input data was used for simulation of soil moisture movement through SWIM. Daily rainfall data for the period (1980-1989) of Barchi raingauge station located in Barchi watershed was considered for the study. Typical rainfall distribution for the year 1995 has been presented in figure 3.

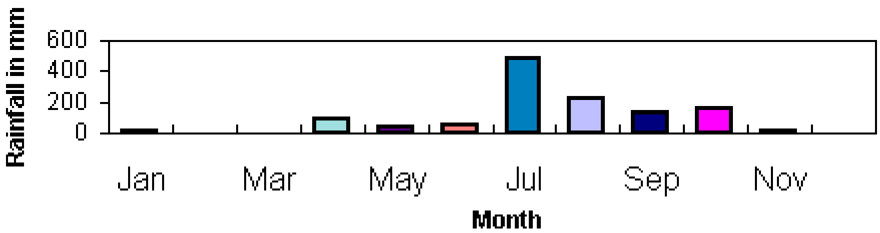


Figure 3. Rainfall Distribution in Barchi Watershed During 1995.

Evaporation: Daily evaporation data Barchi for the period (1980-1989 was considered for the analysis.

Saturated Hydraulic Conductivity: Saturated hydraulic conductivity was measured at 8 locations in the study area by using disc permeameter and Guelph permeameter (locations are shown in fig.1).The average saturated hydraulic conductivity values for the upper layer (0 - 45 cm) and lower layer (below 45 cm depth) were found to be 3.83E-3 cm/hour and 1.61E-4 cm/hour respectively and considered for the study.

Van Genuchten Parameters: The collected soil samples from the study area were analysed in the laboratory by pressure plate apparatus for soil moisture retention characteristics. The averaged van-Genuchten parameters for the two soil layers were obtained by non-linear regression analysis (table 1).

Table 1. Van Genuchten Parameters for the Two Soil Layers.

Layer	Depth range in cm	Van-Genuchten Parameter	
		α	N

Top layer	0- 45	0.0062	1.5158
Bottom layer	45- 150	0..0305	1.3644

Vegetation: Forested watershed, minimum xylem potential = -15000 cm, exponential root growth with depth and sigmoid with time were assumed for the study.

Simulation Results

Using the above input data, SWIM was run for the period 1980-1989. Runoff, evapotranspiration, and drainage were computed from the model, as given in Table.2. Annual rainfall varied between 1000 mm to 2000 mm during the study period, mostly occurring in the monsoon season (June - October). Simulated runoff at Barchi gauging site was found to vary between 273 to 700 mm, evapotranspiration between 620 to 882 mm, and drainage between 57 to 406 mm.

Table 2. Estimated Water Balance in Barchi Watershed using SWIM Model.

S. No.	Year	Rainfall (mm)	Runoff (mm)	Runoff Coeff.	Evapotranspiration (mm)	Drainage (mm)
1	1980	1998.5	699.5	0.35	726.2	299.8
2	1981	1568.5	376.5	0.24	827.7	204.0
3	1982	1782.0	548.1	0.31	767.2	406.0
4	1983	1484.0	479.4	0.32	685.0	319.0
5	1984	1595.0	365.7	0.23	833.2	396.1
6	1985	1256.0	273.0	0.22	882.4	100.9
7	1986	1509.6	493.0	0.33	860.8	156.0
8	1987	1248.5	461.8	0.37	624.5	162.2
9	1988	1665.5	620.0	0.37	859.6	185.4
10	1989	1001.0	493.0	0.49	630.4	57.2

The above results indicate that around 50% of the total rainfall received in the forested watershed escape as evapotranspiration. The average runoff was estimated for the Barchi watershed as 32% (runoff coefficient 0.32). Around 15 % of the rainfall goes as drainage. The runoff component was estimated as 25% by using TOPMODEL for Barchi watershed (UNESCO project report, under publication). Shetty (1999) has reported that the runoff coefficient varies between 0.1and 0.36 (varying with rainfall) for the Barchi watershed by using Conceptual water balance model. Therefore, SWIM model may be used to determine runoff of a forested watershed with reasonable accuracy. Deep percolation in black cotton soils (as prevalent in the study area) is less due to very low infiltration rates as observed by the authors during field investigations for the present study (varied between 2 mm/hr and 6 mm/hr). Due to the presence of high litter and organic matter in the top layer, initial infiltration is relatively high and the moisture remains in the top soil layer due to typical nature of black cotton soil (Purandara et al, 2000).

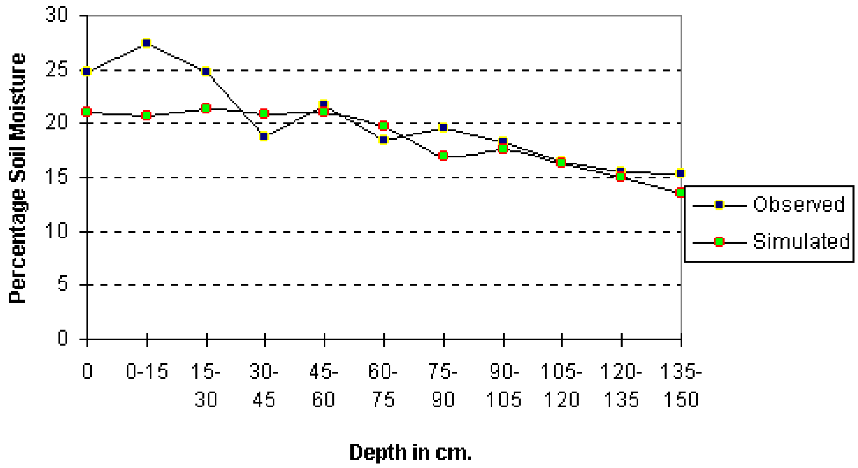


Figure 4. Observed and Simulated Soil Moisture Profile for Barchi Watershed (2nd October 1995).

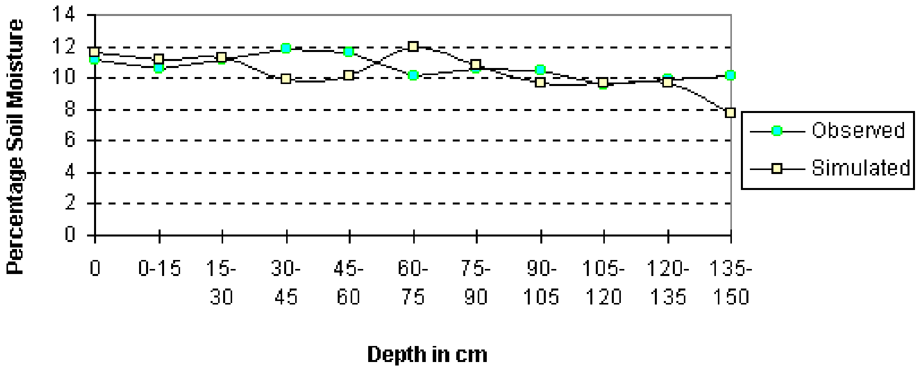


Figure 5. Observed and Simulated Soil Moisture Profile for Barchi Watershed (17th April 1996).

The observed soil moisture profiles were available at Barchi for the days 2/10/1995 and 17/4/1996. Therefore, SWIM was also applied in the watershed for the year 1995-96. The observed and simulated soil moisture profiles for 2/10/95 and 17/4/1996 have been presented in figures 4 and 5. A reasonably good agreement in soil moisture content at various depths was found between observed data and those simulated by SWIM. From figures 4 and 5, it is apparent that the variations of moisture content are dampened at greater depths. The upper layer seems to be more affected by the processes of soil evaporation, plant water uptake and infiltration events.

CONCLUDING REMARKS

The application of SWIM has been demonstrated for a forested watershed in Karnataka, India. The model can be integrated in laboratory and field studies concerned with soil water and solute transport and therefore can contribute in water management planning.

Acknowledgement

Authors are highly grateful to Director, NIH, Roorkee for granting permission to publish the paper.

References

Verburg, Kirsten, P. J. Ross and K. L. Bristow.(1996), "SWIMv2.1 User Manual", Divisional Report, No. 130. CSIRO, Australia.

Lakshman.N. (1993), "Field Soil Moisture Regimes and Hydrology of Irrigated Plots", Ph. D. thesis, Indian Institute of Science, Bangalore.

Shetty, A. V.(1999), "Rainfall-Runoff modelling of Western Ghat Region of Karnataka", Technical Report, National Institute of Hydrology, Roorkee.

UNESCO (2000), "Forest Rehabilitation Strategies in North Kanara District, Karnataka" (under publication), Hard Rock Regional Centre, National Institute of Hydrology, Belgaum.