Simulations on Soil Water Variation in Arid Regions

Dong et al.

Arid regions - favorable sites for storing of nuclear wastes

Soil hydrologic model (SHM) was used for soil moisture simulation

Soil texture and vegetation effects on the soil water variation

Macropores in the soil could affect the soil water flow and distribution

2. Soil Hydrologic Model (SHM)

The SHM was developed to simulate the vertical profile of soil water content and is driven by conventional meteorological and land-use data.

The one-dimensional moisture flow in the SHM can be described (Capehart and Carlson, 1994)

$$\frac{\partial \boldsymbol{q}(z,t)}{\partial t} = -\frac{\partial q(z,t)}{\partial z} + S(z,t) \qquad (1)$$

where q is the vertical moisture flux, *è* is the volumetric water content, z is depth, and t is time. The term S represents a source/sink term which accounts for the rate of input and output of moisture into the soil column. By applying the Darcy's equation in conjunction with Equation 1, the vertical flux term in Equation 1 can be expanded as

$$-\frac{\partial q(z,t)}{\partial z} = \frac{\partial}{\partial z}[K(z,t)\frac{\partial \boldsymbol{y}(z,t)}{\partial \boldsymbol{q}}\frac{\partial \boldsymbol{q}(z,t)}{\partial z}] + \frac{\partial K(z,t)}{\partial \boldsymbol{q}}\frac{\partial \boldsymbol{q}(z,t)}{\partial z}\cos \boldsymbol{b} \qquad (2)$$

where K is the hydraulic conductivity, ψ is the soil water matric potential, and *â* is the grid-surface slope angle.

The van Genuchten and Mualem method is used in this study and can be expressed in the following equations:

Hydraulic conductivity K(θ)

$$K(\theta) = K_s (S_e)^{1/2} \left[1 - (1 - S_e{}^{1/m})^m\right]^2$$

Matric potential ψ(θ)

$$\psi(\theta) = \psi_s (S_e{}^{-1/m} - 1)^{1/n}$$

Where n = λ+1, m = λ/(λ+1), λ is the pore size parameter ($b=\lambda^{-1}$). S_e is the normalized volumetric water content expressed in terms of the soil water content at saturation θ_s, and a residual soil water content θ_r, thus S_e is defined as

$$S_e = \frac{\theta - \theta_r}{\theta_s - \theta_r} \tag{3}$$

Infiltration-runoff calculation

The Green-Ampt (GA) method (Chow et al., 1988) was implemented in the model for the infiltration-runoff calculation

$$f = f(t) = \frac{dF}{dt} = K_{av}\left(1 + \frac{\Delta\psi\Delta\theta}{F}\right) \tag{4}$$

where f is the infiltration capacity (cm/s), K_{av} is the average saturated hydraulic conductivity (cm/s), $\Delta\psi$ is the difference in average matric pressure before and after wetting (cm), $\Delta\theta$ is the difference in average soil water content before and after wetting, and F is the cumulative infiltration for the rainfall event (cm).

Subgrid spatial variability

As a first step in representing variability in hydrologic parameters, the following probability distribution is implemented in the SHM to distribute the average value among subgrid fractions within a grid cell (Yu, 2000)

$$f(p_i) = \frac{1}{P}\exp\left(-\frac{p_i}{P}\right), \int_o^\infty f(p_i)dP = 1 \tag{5}$$

where $f(p_i)$ is the fraction of a grid cell with precipitation p_i, and P is the grid cell average value of hydrologic parameters.

Parameterization of macropore flow

With certain values of macroporosity (the fraction of soil volume comprised of macropores) n_m and the macropore radius probability density $f(r)$ can be calculated by using the following equation

$$f(r) = k_1 \cdot \exp(-k_2 \cdot r) \tag{6}$$

where r is the macropore radius, and k_1 and k_2 are fitting parameters, 0.63 and 0.60 for the fractional macroporosity n_m = 0.01 respectively (Brandes, 1998). So the hydraulic conductivity of macropores for each value of radius can be calculated by

$$K_{mp}(y) = \frac{\int_0^\Gamma K_{mp}(r) f(r) dr}{\int_0^\Gamma f(r) dr} \tag{7}$$

where G is chosen such that $y_{ae}(G) = y$, and the y_{ae} is air entry pressure, so that the weighted sum includes only those pores (r< G) that contribute to flow at a certain matric potential. G is calculated using the following equation

$$\Gamma = \frac{2\sigma \cos\gamma}{\rho g \psi} \tag{8}$$

where σ is the air-water surface tension, γ is the water/pore surface contact angle, (assumed to be 0 for water), ρ is the density of water, and g is the gravitational acceleration. Therefore, the calculated Γ from Equation 8 would be a maximum radius for the macropore.

$K_{mp}(r)$ is calculated using Hagen-Poiseuille's and Manning's equations (Chen and Wagenet, 1992). When $\Gamma < 100$ µm (or 10^{-4} m), the flow in pores can be considered laminar, thus the average flow velocity (U) in the pores is calculated using the Hagen-Poiseuille equation

$$U = \frac{gr^2}{8v}\Delta h \tag{9}$$

where ν is the kinematical viscosity and Δh is the hydraulic gradient. Following the Darcy's equation, the macropore conductivity can be defined

$$K_{mp}(r) = \frac{U}{\Delta h} = \frac{gr^2}{8v} \tag{10}$$

When $\Gamma > 100$ µm, the macropore flow is no longer laminar and the Hagen-Poiseuille equation is invalid to describe flow. In this case, the macropore flow can be described using Manning's formula (Chen and Wagenet, 1992). The average flow velocity is

$$U = \frac{1}{n} R^{2/3} \,|\Delta h|^{1/2} \tag{11}$$

where R is the hydraulic radius (for the special case of full pore flow with radius r, $R = r/2$), and n is the coefficient of roughness, ranging from 0.016 to 0.14 for open channels. Here we assume the upper limit because the scale of the wall surface roughness to pore diameter is generally large. Therefore, the macropore hydraulic conductivity can be calculated using

$$K_{mp}(r) = \frac{U}{|\Delta h|} \cong \frac{(r/2)^{2/3}}{0.14|\Delta h|^{1/2}} \tag{12}$$

$K_{mx}(y)$ is calculated using the van Genuchten's equation (1980), which is expressed as following equation

$$K_{mx}(y) = K_S \frac{\left\{1-(ay)^{n-1}[1+(ay)^n]^{-m}\right\}^2}{[1+(ay)^n]^{m/2}} \tag{13}$$

in which α, n, and m are soil parameters and m = 1-1/n. K_s is the soil hydraulic conductivity at saturation. This equation is valid over ranges of pressure values broader than that of Gardner's exponential model (van Genuchten and Nielsen, 1985). The weighted effective conductivity for each value of y may then be obtained

$$K_{eff}(y) = n_m \cdot K_{mp}(y) + (1-n_m)K_{mx}(y) \tag{14}$$

With macroporosity n_m = 0.01 and 0.001, the computed relations of $K_{eff}(y)$, $K_{mp}(y)$, and $K_{mx}(y)$ for a silty loam are shown in Figure 1.

3. Study Sites

4. Hydrologic Data

5. Results

5.1. Soil texture

5.2. Macropores

5.3. Vegetation