Implementation of Infiltration operator in anugaSed

An infiltration operator was implemented in anugaSed in order to simulate flows in the Colorado River Delta, which is a strongly losing stream.

We implemented the Green-Ampt equation for infiltration (Green and Ampt, 1911) because it is computationally more efficient than the Richards equation. The Green-Ampt equation makes some simplifying assumptions:

- The wetting front moves down into dry soil
- Matric suction pulls water into dry soil
- The soil above the wetting front is saturated

The simplest form of the Green-Ampt equation for infiltration rate, f can be written as:

$$f = -K_s \frac{dh}{dz} \tag{1}$$

where dh/dz is the hydraulic gradient and K_s is the saturated hydraulic conductivity. This can be rewritten as:

$$f = -K_s \frac{h_f - h_o}{Z_f} \tag{2}$$

where h_f is the hydraulic head at the wetting front (sum of matric forces at the wetting front and the weight of the water above), h_o is the hydraulic head at the surface (zero, unless there is water ponded on the surface), and Z_f is the depth of the wetting front. The depth of the wetting front can be related to the cumulative amount of infiltrated water F by:

$$F = Z_f(\theta_s - \theta_i) \tag{3}$$

where θ_s is the saturated moisture content and θ_i is the initial moisture content before infiltration began. Combining these equations, we can write a relationship for the infiltration rate (after water has started ponding at the surface):

$$f(t) = -K_s \frac{h_f - h_o - Z_f}{Z_f} \tag{4}$$

A simpler approach is to recognize that, during an ephemeral flow event, the stream channel surface will quickly become saturated and a positive pressure head, equation to the stream stage, will be exerted at the channel boundary (Freyberg et al., 1980). The velocity of the wetting front can be expressed as:

$$v_f = \frac{f(t)}{\theta_s - \theta_i} = -K_s \frac{h_f - h_o - Z_f}{Z_f(\theta_s - \theta_i)} \tag{5}$$

The time it takes the wetting front to advance a depth Z_f is then:

$$t = \frac{(\theta_s - \theta_i)}{K_s} \left[Z_f + (h_f - h_o)\, ln \left[1 + \frac{Z_f}{h_o - h_f} \right] \right] \tag{6}$$

The rate of advance of the wetting front eventually decreases to a constant value of $K_s/(\theta_s - \theta_i)$.

From Processes Controlling Recharge Beneath Ephemeral Streams in Southern Arizona - Kyle Blasch and Ty Ferre, in Groundwater Recharge in a Desert Environment

Green-Ampt parameters as determined by Rawls/Brakensiek (1993) (Hydrology Handbook) for sand

Porosity: 0.437 (0.374 - 0.5) Wetting front soil suction head (cm): 4.95 (0.97 - 25.36) Saturated hydraulic conductivity (cm/hr): 23.56

From Dingman: Physical Hydrology

After ponding, infiltration rate is given by Darcy's law:

$$f(t) = K_s - K_s \frac{\psi_f + h_o}{Z_f} \tag{7}$$

where ψ_f is the effective tension at the wetting front and h_o is the depth of ponding.

0.1 Implementation

A quantity is created called "wetting front depth" that stores the depth to the wetting front (in meters) for every cell in the landscape. By default, the initial value of this quantity is 0.5 cm (0.0005 m). This is done to avoid calculating infinite infiltration rates.

At every timestep in the simulation, the operator calculates the infiltration rate f for all cells with a minimum flow depth of 1 cm using the equation:

$$f = -K_s \frac{\psi_f - h_o - Z_f}{Z_f} \tag{8}$$

where ψ_f is the effective tension at the wetting from, h_o is the depth of flow, and Z_f is the value of wetting front depth. The infiltration rate is multiplied by the timestep to obtain the streamflow loss (in meters). This value is subtracted from the flow depth.

The value of the quantity wetting front depth is updated by calculting the velocity of the wetting front:

$$v_f = \frac{f}{(\theta_s - \theta_i)} \tag{9}$$

where θ_s and θ_i are the saturated moisture content and the initial moisture content, respectively. The value of v_f is multiplied by the timestep to obtain the change in depth of the wetting front, and the quantity wetting front depth is updated.