Three-layers hydrological model

The hydrological model that will be described here is a continuous model (long-term) at daily time step but is not designed to simulate detailed single-event flood routing. Originally, it was developed by UPC and called 'Easy Bal' model (https://h2ogeo.upc.edu/es/software-hidrologia-subterrania/11-software-hidrologia subterrania/43-easy-bal). Original hydrological model only included two layers to represent the catchment soil: the root zone and the saturated zone (aquifer). This document will introduce a modified version of the model which includes three layers (see Figure 1). The new model is designed to evaluate water balance per unit of soil area as a function of precipitation, the potential evapotranspiration (or ETP), temperature and irrigation. It represents physically the root zone (Layer 1), unsaturated soil (Layer 2) and saturated soil (Layer 3).

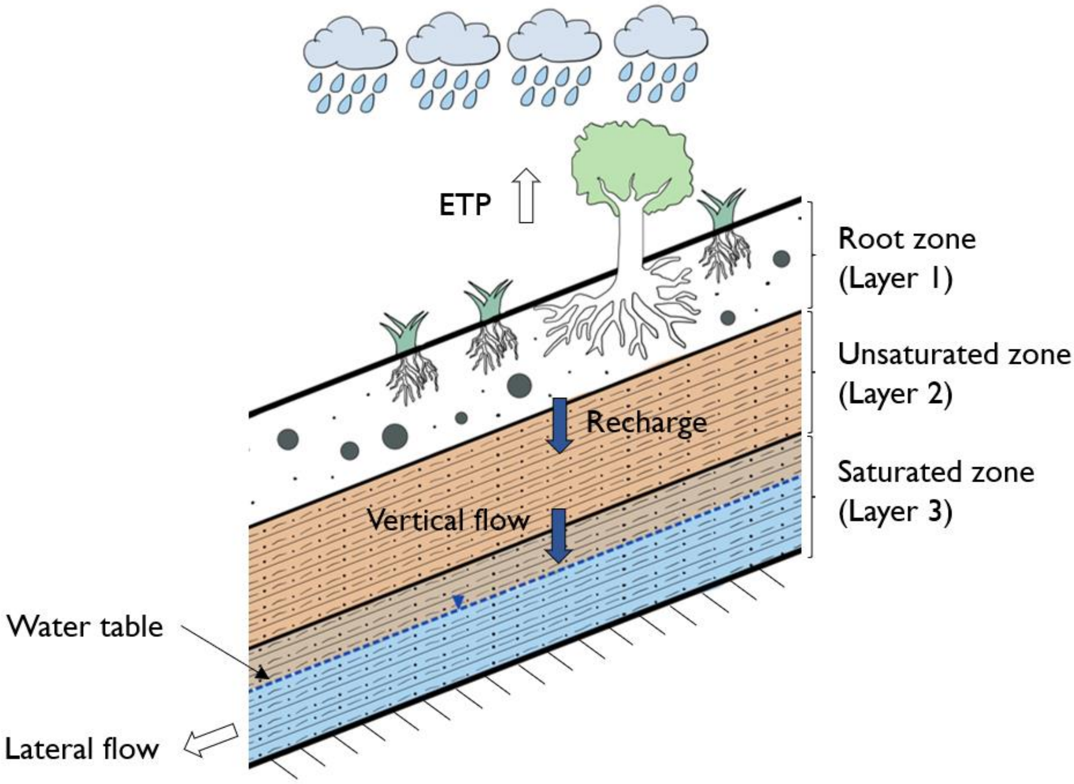

Figure 1.Conceptual representation of three-layers hydrological model

1. Root zone hydrological cycle

The hydrological cycle in the Layer 1 (root zone) is regulated by the rainfall, the evapotranspiration, the runoff, and the infiltration process to the unsaturated zone (recharge). Here, the model consists of six parameters to perform the modelling: latitude, willing point, initial water content, soil thicknesses, soil porosity, and hydraulic conductivity. The water balance is this layer is based on the following equations.

For estimating potential evapotranspiration, the model uses the Hargreaves method, which requires rainfall, maximum and minimum daily temperature data as input.

$$ETP = 0.0023 * R_a * (T_{mean} + 17.8) * (T_{max} - T_{min})^{0.5} \quad (1)$$

Where ETP is the potential evapotranspiration in mm/day, T_{mean}, T_{max} and T_{min} are the mean, maximum and minimum temperature respectively in Celsius (°C). Extra-terrestrial radiation (R_a) is estimated based on the location's latitude and the calendar day of the year.

Runoff process must be specified in the model. In the attached excel sheet, runoff was calculated by Hortonian approach. When rainfall intensity exceeds the infiltration capacity of the soil, the Hortonian overland flow can be divided into a rainfall excess phase and a recession-infiltration phase. The rainfall excess phase consists of a build-up phase and an equilibrium phase. The build-up phase begins when rainfall intensity exceeds infiltration capacity (soil permeability) and ends when water from the uppermost part of the hillslope contributes to the discharge at the outlet. When rainfall excess continues, the equilibrium phase starts, during which the full hillslope contributes to the discharge at the outlet. As soon as the rainfall intensity falls below infiltration capacity, the recession-infiltration phase starts. In the recession-infiltration phase, water still flows overland and continues to reach the outlet, but, increasingly, the upper parts of the hillslope fall dry. When rainfall intensity increases again above infiltration capacity, the process repeats itself .

A simplistic version to estimate runoff from Hortonian approach can be applied. For instance, when rainfall intensity is greater than hydraulic conductivity (soil permeability), runoff is equal to rainfall at time step *i*, otherwise all the rainfall is infiltrated. Hourly rainfall data is highly recommended to be used. Equation (2) can be applied to separate runoff from infiltration:

$$R_i = IF(P_i > K, P_i, 0) \quad (2)$$

Where R_i and P_i are the runoff and rainfall intensity at time step *i* respectively, and *K* is the soil hydraulic conductivity.

Therefore, the model can estimate the soil layer 1 degree of saturation based on the following equation.

$$S_{d\,(layer\ 1)_i} = \max\left(\min\left(\frac{S_{d(layer\ 1)_{i-1}} * n_{t\,(layer\ 1)} + (P - R) - ETP}{n_{t\,(layer\ 1)}}, 1\right), \frac{W_p}{n_{layer\ 1}}\right) \quad (3)$$

Where S_d is the saturation degree at *i* time step, *n* is soil porosity, *P* is precipitation (mm/day), R is runoff (mm/day), W_p is the soil wilting point, n is the soil porosity of layer 1, and n_t is the total amount of available soil pores obtained by multiplying its porosity and soil thickness.

Finally, infiltration process to unsaturated zone (Recharge-*Re*) from layer 1 to layer 2 (in mm) is performed by the following equation:

$$Re = \frac{S_{d_{i-1}} * n_{t\,(layer\ 1)} + (P - R) - ETP}{n_{t\,(layer\ 1)} - S_{d_i}} \quad (4)$$

2. Unsaturated zone hydrological cycle

The hydrological cycle in the Layer 2 (unsaturated zone) is regulated by recharge from Layer 1 and the percolation process to the saturated zone (vertical flow). Here, the model consists of three parameters: soil thicknesses, soil porosity, and hydraulic conductivity. The water balance in this layer is based on the following equations.

Considering layer 1 recharge, saturation degree (S_d) of unsaturated zone is estimated as follow:

$$S_{d\ (layer\ 2)_i} = \min\left(\frac{S_{d(layer\ 2)_{i-1}} * n_{t\ (layer\ 2)} + \max(Re, 0) - F_{v\ (sat)}}{n_{t\ (layer\ 2)}}, 1\right) \quad (5)$$

Where n_t is the is the total amount of available soil pores of layer 2, Re is the recharge from layer 1, and F_v is the vertical flow which estimates the amount of water (mm) that is going into the aquifer (saturated zone). This value is calculated as:

$$F_v = \left(\frac{S_{d(layer\ 2)_{i-1}} * n_{t\ (layer\ 2)} + \max(Re, 0)}{n_{t\ (layer\ 2)}} - S_{d\ (layer\ 2)_i}\right) * n_{t\ (layer\ 2)} \quad (6)$$

3. Saturated zone hydrological cycle

The Layer 3 represents the aquifer and receives the water from unsaturated zone as the vertical flow (F_v). Water output is calculated as Lateral flow (F_l) which represent the water recharge to the aquifer. Two parameters control this layer: initial water table and slope. The water balance in layer 3 is based on the following equations:

Aquifer water table and lateral flow (mm and mm/day respectively) are calculated as follow:

$$WT_i = \min\left(\max\left(WT_{i-1} + \frac{F_{v_{i-1}}}{n_{layer\ 2}} - \frac{F_{l_{i-1}}}{n_{layer\ 2}}, 0\right), WT_d * 1000\right) \quad (7)$$

$$F_{l_i} = WT_i * K * \frac{\sin(\theta)}{1000} \quad (8)$$

Where WT_i is the water table at i time step, n_t is the is the total amount of available soil pores of layer 2, K is the hydraulic conductivity, and θ is the terrain slope.