Research on Unsaturated Flow Model in the Plain of the Huaihe River Basin

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Abstract:

It is crucial important to understand the water cycle in the plains of the Huaihe River Basin not only for forecasting flood, drought and water demand, but also for making short period water withdrawal plan and long period water development scenarios. In th plains, the unsaturated zone played an important role in the water transfer among precipitation, surface water, groundwater, soil water and evaporation due to its linkage position among the water cycle, so the unsaturated flow was important for coupling surface water model and groundwater numerical model. The paper focused the general dynamical unsaturated flow equation, Richard equation, and applied a numerical model to calculate the soil moisture process. The model was applied at Wudaogou Hydrological Experimental Station (WHES). The model was divided into for layers, with a thickness of 5cm, 20cm, 30cm and 35cm from top to bottom respectively. The hydrological data measured at WHES was used to calibrate and verify the model. The measured vertical average soil moisture process was used to evaluate the goodness of the model. The result showed that the simulated vertical average soil moisture process was similar to that of measured, so the model was effective for modeling soil moisture process. However, there were long way to go to apply the model to natural basin due to its complicated heterogeneous and anisotropic soil property, crops and vegetation distribution, geomorphology, and etc.

1 Introduction of the research

1.1 The Natural Condition of the Huaihe River Basin

The Huaihe River was originated from the Tongbo Mountain of Henan, flowed through Anhui and Jiangsu. The total basin area was 270,000km^2, out of which two thirds was of the plain or flooded low land, and the others was mountainous. Corresponding to 15.5*10^6 ha tillage and 0.165*10^9 population (the Huaihe River Commission, 2004), the water resources were scarce the in HRB, and its spatial and temporal distributions were uneven. Nowadays, due to the uneven spatial and temporal distributions of the water resources and increasing water withdrawal, the conflict between water uses and water supply was becoming serious in the plains of HRB, and the water resources development was becoming difficult. However, in the plains, the geomorphology was flat, and the quaternary sediments layer was thick, so the soil layer supplied good condition for water transfer between surface water, groundwater and unsaturated water. The transfer relationships were crucial important for flood forecasting, making reasonable water resources development scenarios and forecasting water uses. In the water transfer processes, the soil water played a very important role. Therefore, it is necessary to build a model to simulate soil water change process.

1.2 Objective of the Research

The research objective of the paper was to build a dynamical unsaturated zone flow model. The model was calibrated and verified by the hydrological data measured in the Wudaogou Hydrological

Experimental Station. After simulating the soil water processes, the annual water budget was analyzed. Then the general relationships were built via the water budget analyses, such as the relationships between groundwater evaporation and groundwater head depth, between annual land evaporation and potential evaporation, between annual precipitation and surface water, between precipitation and groundwater recharge from precipitation, and etc.

1.3 Research Station and Data Source

The research focused on the data measured at Wudaogou Hydrological Experimental Station (WHES), which was located in the north of Bengbu, the west of the railway from Beijing to Shanghai, 30km to downtown of Bengbu roughly. WHES was a large integrated hydrology and water resources experimental station, with an area of 1.4 ha. Groundwater regime observation set consisted of 62 lysimeters and a large field basement with a diameter of 1100m, a depth of 65m. The runoff experimental field consisted of 3 overlap catchments, with the largest area of 136 ha, the middle area of 10 ha, and the smallest area of 0.3ha. There were 16 pumping wells and 2 automatic groundwater head measured wells in the experimental field.

The long-term annual precipitation, potential evaporation, average groundwater head depth were 866mm, 1103mm and 1.14m. The soil was sandy clay loam. The soil moisture constants were measured at WHES, and the result was shown in the table 1.1.

Table 1.1 The soil moisture constants measured at WHES

Depth（cm）	Saturated water content (volume %)	Field capacity（volume %）	Capillary break point（volume %）	Wilting point（volume %）	Moisture absorption point（volume %）
0-20	39.6	30.7	19.5	14.8	7.4
20-40	31.0	25.8	18.1	14.6	7.3
40-60	29.6	26.5	18.6	14.4	7.2
60-80	28.8	25.2	17.6	15.8	6.9
80-120	27.5	24.8	17.4	15.6	7.8
120-200	27.4	24.6	17.3	16.4	8.2

The data observed at WHES applied in the research included followings:

(1) The daily meteorological data from 1994 to 2000, such as precipitation, air temperature, ground temperature, air humidity, wind velocity, solar radiation and water surface evaporation measured with evaporation pan.
(2) The daily soil moisture content in the depths of 5, 25, 35, 45, 55, 70 and 90cm from 1994 to 2000.
(3) The daily groundwater head (and its depth).
(4) Crops type, soil property.

2 Unsaturated Flow Model

According to Richard equation, the dynamical unsaturated flow process can be simulated by equation 2.1.

$$\frac{\partial\theta}{\partial t}=\frac{\partial}{\partial z}(D\frac{\partial\theta}{\partial z})+\frac{\partial K}{\partial z}+F(t,\theta) \tag{2.1}$$

where K and D were conductivity and diffusion coefficient of unsaturated zone respectively, and they were functions of soil moisture, θ. Here the equation 2.2 and 2.3 were applied to estimated K and D.

$$K(\theta)=K_s(\theta/\theta_s)^{2b+3} \tag{2.2}$$

$$D(\theta)=K(\theta)(\partial\Psi/\partial\theta) \tag{2.3}$$

$$\Psi(\theta)=\Psi_s/(\theta/\theta_s)^b \tag{2.4}$$

where, K_s and Ψ_s were soil conductivity and potential of saturated zone respectively, and b was a empirical coefficient, and they were function of soil property (Cosby et al., 1984). $F(t,\theta)$ were sinks and sources, such as precipitation, evaporation, runoff, and etc.

In the research, the soil layer was from land surface to 90cm depth. In the range, the soil moisture might be calculated with four layers model, so the Richard equation might be rewritten to equation 5 ~ 8 (Chen F., et al. , 1994a, b. Chen Xi, et al, 2004).

$$d_1\frac{\partial\theta_1}{\partial t}=-D\left(\frac{\partial\theta}{\partial z}\right)_1-K_1+P_d-R_s-E_u-E_{T1} \tag{2.5}$$

$$d_2\frac{\partial\theta_2}{\partial t}=D\left(\frac{\partial\theta}{\partial z}\right)_1-D\left(\frac{\partial\theta}{\partial z}\right)_2+K_1-K_2-E_d-E_{T2} \tag{2.6}$$

$$d_3\frac{\partial\theta_3}{\partial t}=D\left(\frac{\partial\theta}{\partial z}\right)_2-D\left(\frac{\partial\theta}{\partial z}\right)_3+K_2-K_3-E_{T3} \tag{2.7}$$

$$d_4\frac{\partial\theta_4}{\partial t}=D\left(\frac{\partial\theta}{\partial z}\right)_3-D\left(\frac{\partial\theta}{\partial z}\right)_4+K_3-K_4 \tag{2.8}$$

where d_1, d_2, d_3 and d_4 were the thickness of layer 1 to 4 from the land surface to 1m depth soil respectively, K_1, K_2, K_3 and K_4 were the conductivities of layer 1 to 4 respectively, P_d was effect rain, runoff R_s was surface runoff, E_u and E_d were soil evaporation via shallow and deep layers, ET1, ET2 and ET3 were evapotranspiration via the leaves and root of vegetation in layer 1 to 3 respectively.

If groundwater head depth was deeper than the threshold of groundwater evaporation depth, the groundwater evaporation would be neglected, then the lowest layer flow equation can be written to equation 2.9.

$$d_4\frac{\partial\theta_4}{\partial t}=D\left(\frac{\partial\theta}{\partial z}\right)_3+K_3-K_4 \tag{2.9}$$

After replace the differential equations with difference equations approximately, Equation 2.5 ~ 2.9 can be solved from an initial soil moisture condition measured in advance, and the soil moisture series might be calculated for every layer.

3 Model Application at Wudaogou Hydrological Experimental Station

The daily data of soil moisture (θ), precipitation series(P), runoff (R_s), groundwater head and its depth, and groundwater evaporation (E_u, E_d) measured at WHES were applied to the model to simulated soil moisture process. The whole simulated soil layer was from land surface to 90cm depth, and it was divided into four layers with a thickness of 5cm, 20cm, 30cm and 35cm from top to bottom respectively. The parameters about the soil property tested at WEHS were applied in the model, and they were shown in Table 1.1.

After input the daily precipitation, open water evaporation, groundwater depth and the parameters bout the soil property measured at WHES, the vertical average soil moisture from land surface to 90cm depth might be calculated. The results were shown Figure 3.1.

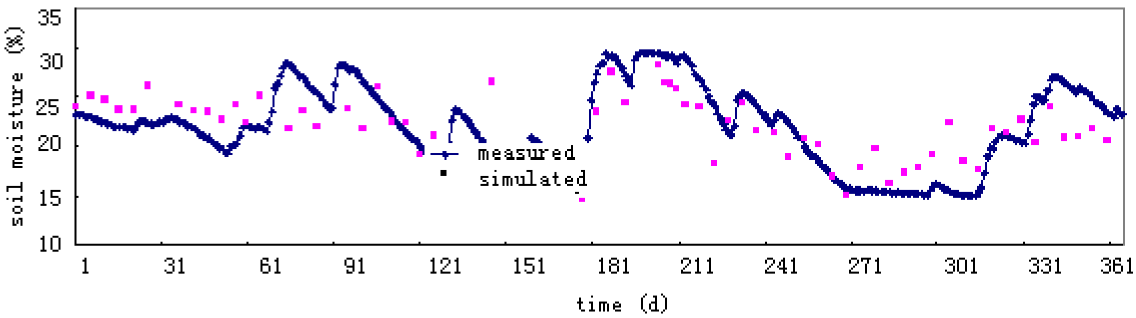

Figure 3.1 the soil moisture process of 1997

4 Conclusions and Recommendations

The result showed that the unsaturated model might be applied to simulate the soil moisture process at WHES. The simulated series were similar to that of measured.

The unsaturated model was the core of the four kinds of water transfer model, so it might be applied to link the surface water model and groundwater dynamical model. Therefore, an integrated model might be built in the next step research. However, it was very difficult to apply the unsaturated model in natural basin due the constraints of land surface property data, such as geomorphologic data, vegetation and crops cover data, soil grain data, irrigation data, conductivity in different point and direction, and so on. Another constraints for the model application was the soil property parameters changed rules, such as conductivity, K, soil potential, Ψ, and diffusion coefficient, D, changed processes with the soil moisture. For understand the relationships mentioned above, a lot of experiment needed to be done.

Finally, the paper only took some consideration on vertical flow of soil moisture. If the model was applied to natural basin, the horizontal direction flow had to be thought over.