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Original Research Paper

# Research on a New Physical Based Hydrological Model Applied in Ebinur Lake Basin in China

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## ABSTRACT

The physical based hydrologic model based on grid-scale for water resources management (WYJ) was applied into the Ebinur Lake basin in Xinjiang Province, China. Several physical parameters were considered in this model and calculated based on the physical properties by combination with GIS tools. We have considered the warm-up period in order to reduce the error accoused by the uncertainty produced from the physical model. After the calibration and validation of the model, the results showed that the model was able to simulating the basin hydrological processes with high efficiency especially in ground surface. The N-S efficiency coefficient was once exceeded 0.85 in simulation periods and $R^2$ can also reach 0.92. We can draw a conclusion that this physical model can be applied into the Ebinur Lake basin and can provided for decision making for the government.

## INTRODUCTION

As the natural hydrology behaviours were greatly changed by human activities in agriculture basins, human effects such as irrigation strategies, and the arrangements of ditch drains make the mechanisms of the runoff generation more complicated (Dunn & Mackay 1996, Moussa et al. 2002) and should be integrated in distributed hydrologic model system. The integrated distributed hydrologic model for agricultural basin water resources management (WYJ) has been developed as a tool to deal with main characters of agricultural basin, such as irrigation strategies and ditch arrangement, etc. A layered infiltration model, GALS, and a multiple maps based digital channel extraction method for agricultural basin were adopted for considering agricultural characteristics in the WYJ model. The physically based, integrated distributed hydrology model is capable of continuous simulation for long time agricultural water management evaluation. The general structure and theory employed in the WYJ model have been described in a companion paper (Liu et al. 2012). The present paper will focus on the application of the WYJ model to Ebinur basin in downstream Jinghe River for agricultural water management analysis.

Application of the WYJ model to an agricultural basin involves four major steps: (1) preprocessing of spatio-temporal data; (2) parameters estimation; (3) spatial domain conceptualization; and (4) model validation and scenarios analysis. In this paper, the study basin, GIS database and parameters estimation will be described first. Then the basin will be divided into several sub-areas and subdivided into a grid network within each sub-area. In the last part, the model will be validated and used to estimate the agricultural water resources in the Ebinur basin. The effects of irrigation strategies will be evaluated and discussed subsequently in detail.

## MATERIALS AND METHODS

**The study area**: Aibi Lake valley location is between 43°38'-45°52'N and 79°53'-85°02'E. Basin is across Mongolia Autonomous Boertala Bole City Jinghe county (Fig. 1). Drainage area of the basin is 47689.04 km².

**Data collection and parameters estimation**: The database for the application of WYJ model includes a great amount of spatio-temporal distribution of data such as hydrology data, meteorology data, topography data, soil data and water usage data, etc. The parameters in the WYJ model can be determined according to the spatial database or measured by field experiments.

Event daily discharge, rainfall and pan evaporation were

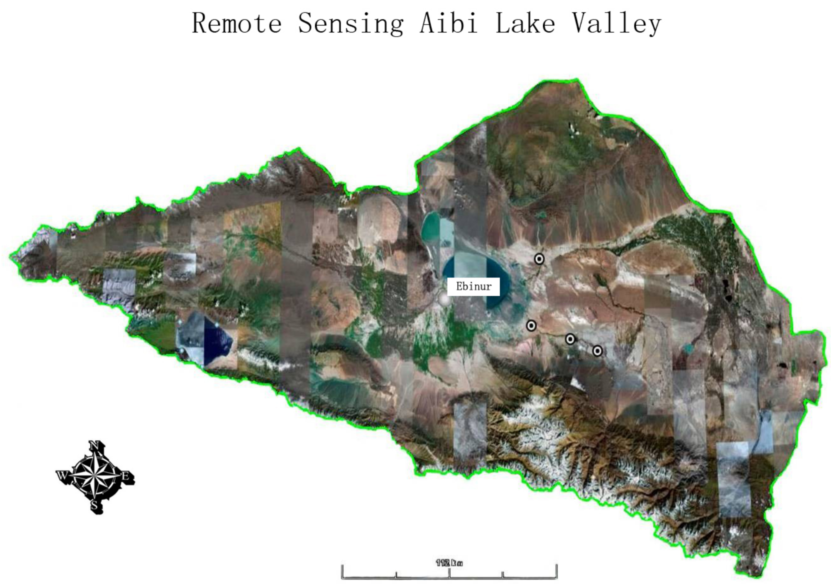


Fig. 1: Ebinur basin.

monitored at the Jinghe station (Fig. 1). Event daily precipitation was also monitored at 11 hydrological stations in the basin (Fig. 1). And there are two hydrological stations on Jinghe River. The groundwater table was measured at 57 cells throughout the basin as shown in Fig. 1. Hydrological data from 1980 to 1985 were used in this study while groundwater table data observed every five days, are from 1980 to 1983. There are two meteorological stations (Fig. 1) including the station in our State Experimental Station of Agro-Ecosystem. The spatial distribution of the precipitation was obtained using Thiessen polygon interpolation method.

Fig. 2. shows schematic description for WYJ model and processes modelling. A DEM for the basin, shown in Fig. 2, was available from the U.S. Geological Survey's EROS Data Center (GTOPO30). Elevations in GTOPO30 were regularly spaced at 30-arc seconds (about 1 kilometre). The ETM landuse data from the Global Land Cover Facility (GLCF) (http://glcf.geodata.cn) were used.

The Albedo coefficients for naked soil surface were calculated through a method (Van Bavel & Hillel 1976) by considering surface soil moisture. Vegetation interception coefficient, IC = 0.24, suggested by Zhu et al. (1997) for semi-arid agricultural catchment, was used with a correction for the Ebinur basin in accordance with this daily model. Manning coefficients for overland flow and channel flow models were also determined by land use data. The initial values were set by referring to field experiments by Woolhiser (1975) and calibration results of rainfall-runoff simulation by Liu et al. (2009).

As the basin is adjacent to the Jinghe River, it was an alluvial by sedimentation of the river repeatedly. So the geological data indicate that the study area is underlain by sandy loam throughout the aquifer with several sand and boulder layers in it. The shallow aquifer is 20-30 m thick with sandy loam and the hydraulic conductivity and specific yield are 5.83cm/hr and 0.07, respectively (Ren 1985).

**Boundary, initial conditions set and its effects:** The WYJ model developed in this study for Xinjiang integrates nearly whole important hydrological processes in agricultural basin. Thus, different processes provide boundary conditions reciprocally. For example, results of river flow routing model for the Jinghe River were used as the second type of boundary condition i.e., head condition for unconfined groundwater model. The driven power of hydrological cycle in this model is meteorological factors such as precipitation, sun radiation, etc.

Soil water balancing is important as it directly determines its recharge with groundwater, rainfall infiltration and surface runoff, etc. Meantime, the soil water flow speed with an order of magnitude around 10-6-1 mm/hr is relatively slower than the speed of surface flow (1 m/s) and groundwater flow (1 cm/hr). So soil water balancing will be the last achieved in the modelling. And it will greatly impact the predictions whether or not considering the balancing time with arbitrary initial condition for soil moisture.

Fig. 3 results for model warming up show the simulated average saturation ratio for top 50 cm soil (0-50 cm) as a function of time in 1980. Eight different initial volumetric soil water content values were used: SW1 (12.5%θfc), SW2

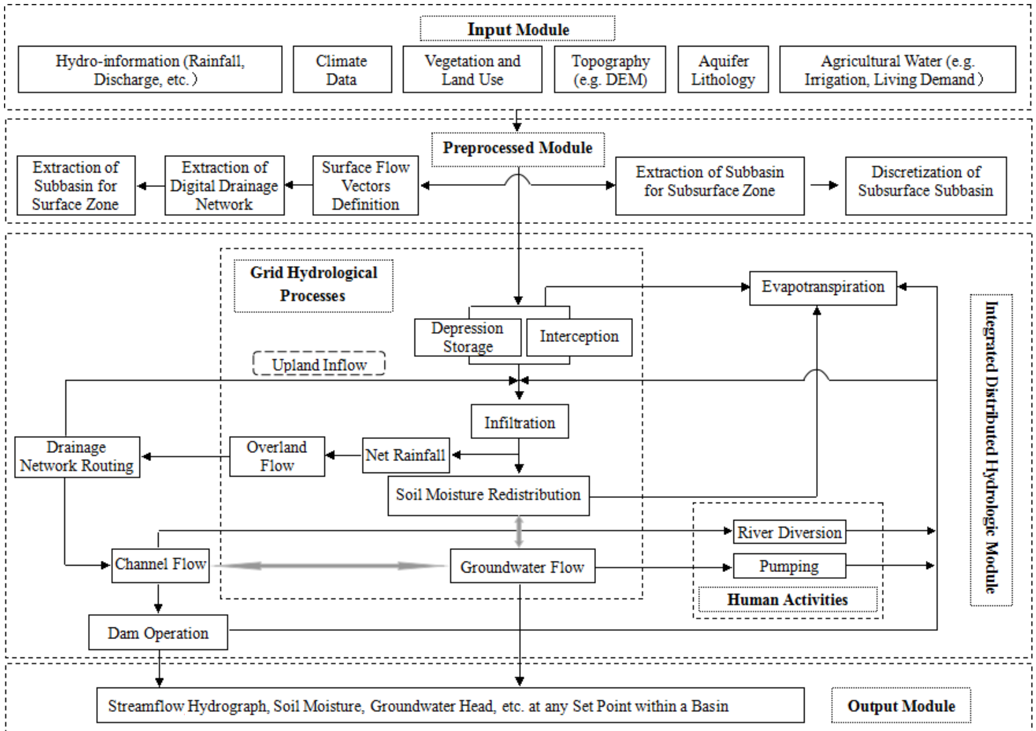


Fig. 2. Schematic description for WYJ model and processes modeling.

(25.0%θfc), SW3 (37.5%θfc), SW4 (50.0%θfc), SW5 (62.5%θfc), SW6 (75.0%θfc), SW7 (87.5%θfc) and SW8 (100%θfc). The dark line is the standard deviation for the eight traces as a function of time. Note that the eight simulation results converge towards a single solution in response to meteorological influences. The convergence is due to the responses of infiltration and evapotranspiration to soil moisture. For example, increased rainfall infiltration and lower evapotranspiration occur with dry soil, whereas increased evapotranspiration and deep percolation occur with wet soil. A model simulation can be considered adequately balanced when standard deviations for different initial conditions become steadily low.

It can be figured that the average soil moisture processes for 0-50 cm have a great bias from January to May and standard bias will never be steadily low until the end of May with a steady standard bias 0.0035. Obviously, initial soil moisture conditions will greatly affect the simulation results and the effects will decrease with time. Another conclusion is that it is necessary for distributed hydrology model to warm up before a balancing state is achieved. Soil water balancing provides a key distinguish sign for model balancing.

**Assessment of model performance:** The following statistical criteria were used to quantify the model performance:

Efficiency Coefficient, EC:

$$EC = 1 - \frac{\sum_{i=1}^{n}(Y_{iobs} - Y_{isim})^2}{\sum_{i=1}^{n}(Y_{iobs} - \overline{Y}_{obs})^2} \quad ...(1)$$

Average Bias, AB:

$$AB = \frac{1}{n}\sum_{i=1}^{n}(Y_{iobs} - Y_{isim}) \quad ...(2)$$

Root Mean Square Error, RMSE:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(Y_{iobs} - Y_{isim})^2} \quad ...(3)$$

Where n is the number of data series; $Y_{obs}$ is observed variables; $Y_{sim}$ is simulated variables and $\overline{Y}_{obs}$ is average value of observed values.

## RESULTS AND DISCUSSION

**Model validation:** The WYJ model was applied to continuous six years hydrological processes from 1980 to 1985 in the Ebinur basin. In order to eliminate the effects of initial conditions and parameters, the model was warmed up and calibrated by using the data in 1980. Fig. 3 gives some results for model warming up as discussed in above Section. The grid size used in this study is 1 km × 1 km for represent-

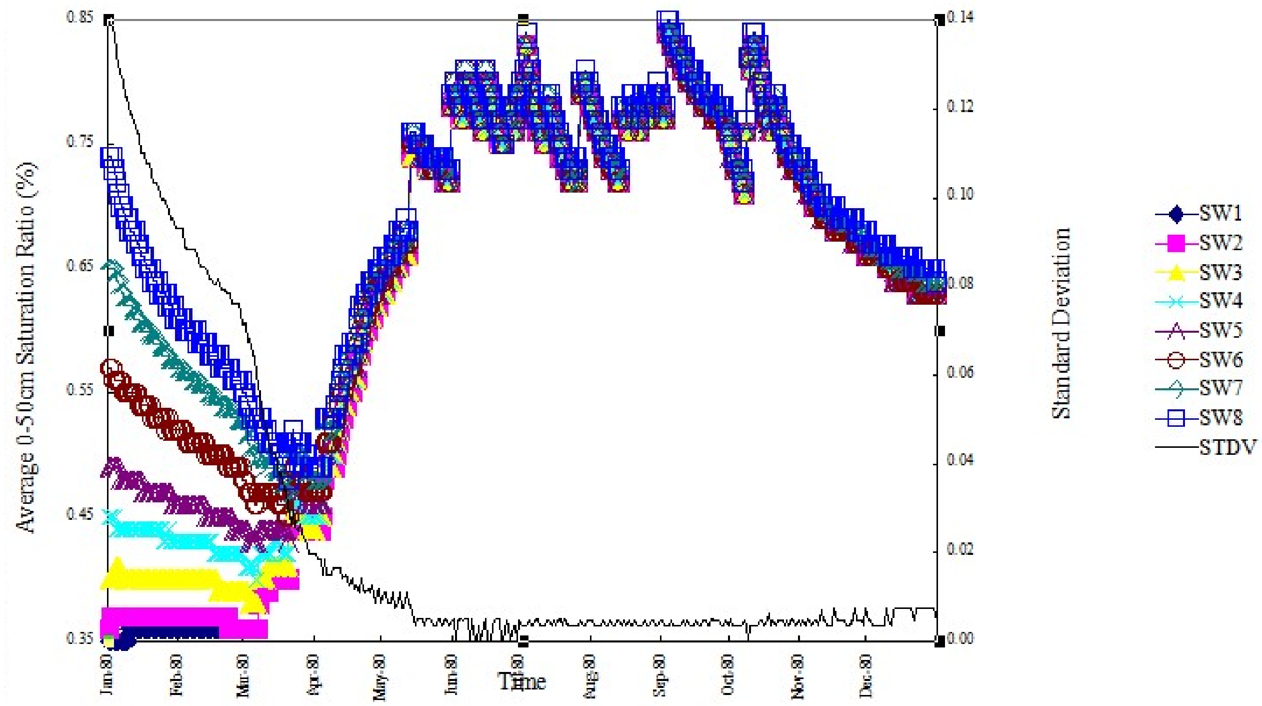


Fig. 3: Results for model warming up.

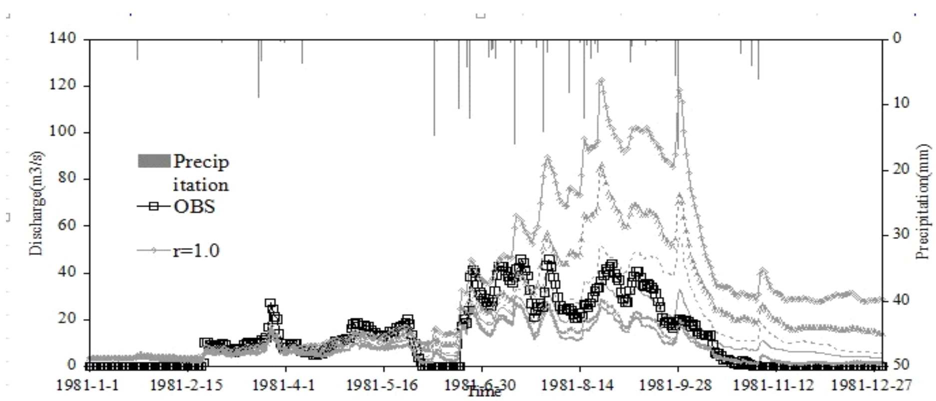


Fig. 4: The simulated results were compared commutatively with the observed ones.

ing spatial heterogeneity of hydrological processes. The hydrological data given in daily interval (except for groundwater level at five days interval) was used for model validation. The actual computation time intervals vary in the simulation according to different processes. For the overland flow and channel flow, the computational time intervals were averaged 50s and varied with terrain slope. The computation time intervals for groundwater model were fixed at 6 h for all simulation events, while for the infiltration model time interval was 1h. Other sub-models' time step was 1 day. Since the model outputs are daily processes, all the results with one day are output of the model by a daily cumulated or averaged value. It showed the observed and simulated discharge at Jiahetan Station on the Jinghe River, and the R-square is about 0.96 by comparing these two processes. The simulated process matched the observed one with the efficiency coefficient, EC is equal to 0.95. The Average Bias, AB is 34.2 $m^3/s$ and the root mean square error, RMSE is 6.5 $m^3/s$. The simulated discharge volume is 5.3% less than the observed volume. The simulated discharge volume is 5.6% less than the observed volume and all the annual biases are around ± 10%. Since the first year was used as model warming up and calibration period, many modes such as soil flow, groundwater can not achieve a balanced condition in very short time and the errors of simulated results in 1980 are larger than other years (e.g. discharge volume bias is -18.6%). The observed and simulated 57 cells-averaged groundwater table (1980 -1983) for the Ebinur basin and the average bias, AB is about 0.04m and the efficiency coefficient, EC equals to 0.79.

**The effects of irrigation strategies on hydrological cycle:** The agricultural water consumption for crops is the overwhelming in the Ebinur basin and the irrigation water is nearly 97 percent of total water supply as introduced in above section. Water demanding for crop growth in this basin is from three sources: natural precipitation, groundwater pumping and water diversion from the Jinghe River. A statistics showed that the water from groundwater pumping was about 28% of total irrigation volume from 1980 to 1985 (Xinxiang Department of Water Conservancy, 1949-2003). So the percentage of the pumping water among total irrigation volume was defined as the irrigation ratio $r$, which is not fixed and is varied for different years according to dry or wet hydrometeorological conditions in the basin or the Jinghe River. In present paper, we do not aim to study when and where groundwater should be pumped for irrigation, but we want to show the effects of irrigation strategies on hydrological cycle by the WYJ model and to give some profound suggestions for decision strategy and evaluate water resources for versatile prospects.

The driest year 1981, according to the hydrological recording since 1950s, was chosen for this study. The cumulative precipitation is 289mm. As the irrigation volume is larger in drier year, both the water diversion from the Jinghe River and groundwater pumping tend to be larger than other years. Then the simulated results were compared commutatively with the observed ones as listed and shown in Fig. 4.

The simulated results (Fig. 4) were compared commutatively with the observed ones. As we assume that crops water demands for sustaining stable yielding was guaranteed, the different irrigation modes nearly have no effects on the simulated annual mean soil saturation ratio. When $r = 0$ and $r = 0.1$, the soil moisture content is higher than other scenarios. The reason is that the groundwater depth in many grids is less than 0.5m in these two scenarios and the soil within these grids is saturated. The discrepancy of actual evapotranspiration (AET) among all the scenarios is about 16 mm. It is very closely related in terms of the soil moisture content, and higher soil moisture content usually corresponds to higher AET. Since the mean soil moisture content is nearly invariant in different scenarios, deep soil percolation is also hardly influenced. However, the percolation volume increases along with the groundwater depth (GWD) increases till $r = 0.7$, and the percolation volume will decrease as $r \geq 0.7$. This seems to indicate that there is a critical depth in the mechanism of deep soil percolation though the percolation is totally stable and less variable than other processes. The percolation volume tends to increase above the critical depth, while decrease below this depth.

The GWD less than 0.5 m and 0 m is only 1.6% and 1.1% of the total area. As the groundwater table rises, the groundwater depth decreases and groundwater within many grids even outcrops the ground. The capacity of soil moisture storage declines and the probability for runoff yielding from saturation excess except infiltration excess increases. And runoff volume is increased by nearly $5.6 \times 108$ $m^3$ as $r$ decreases from 1 to 0. This means irrigation strategies such as water diversion from outside of the basin or groundwater pumping in the basin would greatly affect the local hydrological response. As $r$ is increasing, the runoff volume at Jiahetan station on the Jinghe River decreases. However the influence is relatively small and the discrepancy is between ±2%, which indicate that irrigation demand of the Ebinur basin has little effect on run-off volume on the Jinghe River. Moreover, the recharge pattern between groundwater and inner-channels is altered as $r$ increases. When $0 < r < 0.3$, groundwater will recharge inner-channels and when $r > 0.3$ inner-channels will recharge groundwater.

## CONCLUSIONS

Basin scale hydrology modelling integrating whole hydrological processes based on hydrological mechanism provides an accurate and rapid way for water resources evaluation. In this study, the integrated distributed hydrology model for agricultural basin water resources management, WYJ that is developed for quantification of water availability in view of environmental changes by humanity activities and climate changes over semi-humid and semi-arid agricultural basin, is applied into the Ebinur basin.

A large amount of spatio-temporal data, e.g. land use, soil, hydro-meteorological data and crops, etc., are input into the model for parameters determination and model driven. Though the WYJ model is a process-and physically-based distributed hydrology model and most of parameters in this model are physically measurable in the field or derived from their physical meaning, at least in principle, it still needs a warm-up period of about 5-6 months to eliminate the effects of initial conditions. So, in this study, one year long time, i.e. 1980, is believed reasonable for model warm-up and parameters calibration to reduce the effect by the arbitrary initial conditions. The validation results show that the model is capable of simulating the whole hydrological processes especially with high efficiency at routing surface water. The efficiency coefficients exceed 0.85 and the forecasted runoff errors are all limited by about ±10%.

The water balance of the studied basin is not only affected by meteorological factors as precipitation but also influenced by recharge and water diversion from the Jinghe River. So the irrigation strategies, i.e. how much water is from water diversion from the Jinghe River or groundwater pumping, affect the whole basin hydrological cycle. A scenario analysis with variable irrigation ratio (*r*) between water diversion from the Jinghe River and groundwater pumping has been studied. The results show that different ratios of sources of water for irrigation will greatly affect the basin water balance. The mutual recharge between groundwater and the Jinghe River or inner channels is also altered. With groundwater pumping increasing, the flux at first flows from groundwater to inner-channels and then turns to the contrary direction.

The application of the newly developed WYJ model to the Ebinur basin has produced very promising water budget prediction results. It is encouraging that such an integrated distributed hydrological model can be successfully applied for agricultural basins to solve and evaluate some management strategies, e.g. irrigation practices. Though, needed to be verified in more basins, the model holds promise to any agricultural basin calling for water resources planning and evaluation of crops practices, to a rural village or a county for making irrigation decisions.

## ACKNOWLEDGEMENTS

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## REFERENCES

Dong, Z.G. 1985. Characteristics of leaf area and sunlight utilization coefficient in crop fields of the Xinjiang. In: Zuo D.K. Ed. Management and Development of the Xinjiang. Science Press, Beijing, pp. 163-175.

Dunn, S.M. and Mackay, R. 1996. Modelling the hydrological impacts of open ditch drainage. Journal of Hydrology, 179(1): 37-66.

Kang, S.Z., Liu, X.M. and Xiong, Y. Z. 1994. Theory of water transport in soil-plant-atmosphere continuum and its application. Water & Power Press, Beijing, China.

Liu, J. T. 2012. Digital drainage network automatic extraction software. DigitalHydro V1.1. China Software Copyright, No. 2012SR033528.

Liu, J. T., Chen, X., Zhang, J. B. and Markus, F. 2009. Coupling the Xinanjiang model to a kinematic flow model based on digital drainage networks for flood forecasting. Hydrological Processes, 23(9): 1337-1348.

Liu, J.T., Zhang, J.B., Li, X.P. and Liu, J.L. 2010. Deriving drainage networks and watershed area: A methodology coupling digital elevation model and multiple information. Geography and Geo-Information Science, 25(2): 120-125.

Liu, J.T., Zhang, J.B. and Chen, X. 2012. An integrated distributed hydrologic model for agricultural basin water resources management (WYJ): Theory and structure. Journal of Arid Land (In Press).

Moussa, R., Voltz, M. and Andrieux, P. 2002. Effects of the spatial organization of agricultural management on the hydrological behavior of a farmed catchment during flood events. Hydrological Processes, 16(2): 393-412.

Ren, H.Z. 1985. Regionalization of shallow groundwater in the Xinjiang. In: Zuo, D.K. 1985. Management and Development of the Xinjiang. Science Press, Beijing, pp. 70-79.

Van Bavel, C.H.M. and Hillel, D.I. 1976. Calculating potential and actual evaporation from a bare soil surface by simulation of concurrent flow of water and heat. Agricultural Meteorology, 17(6): 453-476.

Xinxiang Department of Water Conservancy 2003. Xinxiang Annual Reports of Water Resources for 1949-2003. Department of Xinxiang Water Conservancy, Xinjiang, China.

Zhu, A. N. 2008. Efficient Methods Estimating Soil Hydraulic Properties in Tianranwenyanqu (EBINUR) Basin. Ph.D. Dissertation. Graduate School of Chinese Academy of Sciences, Beijing.

Zhu, A.N., Zhang, J.B., Chen, X.M. and Chen, D.L. 2003. Study on pedotransfer function in Fengqiu. Acta Pedologica Sinica, 40(1): 53-58.

Zhu, T.X. Band, L.E. and Vertessy, R.A. 1997. Continuous modeling of intermittent stormflows on a semi-arid agricultural catchment. Journal of Hydrology, 226(1-2): 11-29.