Study on hydrological process simulation of lumped hydrological model in Wujiang River Basin

Guangru Sun1,a, Jie Wen1, Jinjin Yang1, Siyu Hou1 and Weihua Zhang1,b*

1College of Resources and Environment, Southwest University, No.2 Tiansheng Road, Beibei District, Chongqing 400715
aemail: sun138@email.swu.edu.cn
b*Corresponding author:bemail:zhangweihuafes@swu.edu.cn

Abstract. In this paper, AWBM, Sacramento, Simhyd and TANK models were used to simulate the runoff process of Wujiang River Basin from 1991 to 2004. The results show that the Nash-Sutcliffe efficiency coefficients and the relatives of the Simhyd model during verification period are 0.844 and 9.015% respectively, which meet the requirements and achieve the optimal effect. While the AWBM model has a poor performance in the simulation of runoff during flood rise period, a better performance in the simulation of runoff during flood recession period. Sacramento model has obvious "equifinality for different parameters" phenomenon due to its large number of parameters.

1. Introduction
There are a large number of water conservancy and hydropower projects in Wujiang River Basin. The study of runoff process in Wujiang River Basin is of great significance to the operation of water conservancy projects in Wujiang River Basin. The rivers in the Wujiang River Basin are typical mountain rivers, and their hydrological processes show great time-space differences. Sloping runoff generation is often a mixture of superpermeability runoff generation, full storage runoff generation, surface downflow generation and countercurrent generation, and the calibration of parameters is relatively complex. Xiong Jinhe et al. carried out real-time correction for the Wujiang River basin according to the characteristics of "forecast-dispatch-forecast" rolling cycle, so as to improve the prediction accuracy of the water level of the station in the reservoir area affected by cascade reservoirs.

In this paper, the Wujiang River Basin was taken as the study area, and four conceptual lumped hydrological models were used to simulate the runoff process of the basin. The simulation results of different models were compared and analysed, and the runoff process simulation based on the conceptual model in the Wujiang River Basin was analysed.

2. Materials and Methods
2.1. Profile of the study area
This paper takes Wujiang River Basin as the research area. Wujiang River is the largest tributary of the south bank of the Yangtze River, whose main stream flows through Guizhou Province and Chongqing City from west to east, with a total length of about 1030km, a natural drop of about 2120m and a basin area of 87920 km².
Wujiang River is a pinnately distributed river network with a high density. There are 58 well-known first-level tributaries, of which 42 have a basin area of more than 300km², and 16 have a basin area of more than 1000km². The average annual precipitation in the basin is 1163mm, and the precipitation distribution showed temporal and spatial diversity. The spatial distribution is greater in the downstream than in the upstream and greater in the right bank than in the left bank. In terms of time distribution, 88% of the precipitation was concentrated in April to October, and 70% was concentrated in May to September. The average runoff of the Wujiang River Basin (above Wulong) for many years is 49.5 billion m³, and the runoff during the flood season from May to October accounts for 77%-83% of the whole year.

2.2. Methods
Based on the Rainfall Runoff Library software, this paper selects four lump-type hydrological models, AWBM, Sacramento, Simhyd and Tank, and inputs watershed characteristic parameters. Nash efficiency coefficient is used to calibrate the model parameters, and SCE-UA algorithm is used to automatically optimize the model. The selected data were the daily rainfall and evaporation data from 11 rain-measuring stations in Wujiang River Basin and the daily runoff data from Wulong Hydrological Station during 1991-2004. The data from 1991-2001 were used as model calibration and the data from 2002-2004 were used as model verification. The drainage and the distribution of rain gauge stations in Wujiang River Basin is shown in Figure 1.

2.3. Standard for error assessment
(1) The Nash-Sutcliffe efficiency coefficient R², the closer the coefficient R² is to 1, the better the simulation effect will be. It is generally believed that the Nash-Sutcliffe efficiency coefficient reaches
0.6, and the simulation is qualified.

\[ E = 1 - \frac{\sum_{i=1}^{N}(O_i - S_i)^2}{\sum_{i=1}^{N}(O_i - \bar{O}_i)^2} \]  

(1)

Where: \( O_i \) is the observed flow; \( S_i \) is the simulated flow rate; \( i \) is the time step; \( N \) is the total duration of observation.

Relative error of flood volume

\[ R_e = \frac{|R_{sim} - R_{obs}|}{R_{obs}} \times 100\% \]  

(2)

Where, \( R_{sim} \), \( R_{obs} \) are respectively the simulated and observed values of field flood flow, m\(^3\)/s; \( R_e \) is the relative error of the flood discharge of each field, %. The average value of all the fields is taken to be the average relative error of the flood discharge of the basin, and ±10% of the measured value is taken as the permissible error.

3. Results

3.1. Analysis of calibration results

The Nash-Sutcliffe efficiency coefficient NSE and flood volume relative error Re of the simulation run of the four models in the calibration period and verification period are shown in Table 1.

Table 1. Nash-Sutcliff coefficient and error parameters of AWBM, Sacramento, SIMHYD and TANK models.

|            | AWBM  | Sacramento | SIMHYD | TANK  |
|------------|-------|------------|--------|-------|
|            | calibration | verification | calibration | verification | calibration | verification | calibration | verification |
| NSE        | 0.939 | 0.773      | 0.872  | 0.688 | 0.876  | 0.844 | 0.906      | 0.741      |
| RE%        | 5.359 | 14.708     | 9.322  | 8.714 | 9.075  | 5.050 | 8.714      | 1.477      |

In terms of efficiency coefficient, the operating results of the four models in the calibration period and verification period all meet the requirements. While the NSE of AWBM model and TANK model in the calibration period reaches above 0.9, 0.939 and 0.906 respectively, it is only 0.773 and 0.741 in the verification period. The NSE in the verification period of Sacramento model is only 0.688, which just meets the requirements. The performance of SIMHYD model was consistent in the calibration period and verification period, with values of 0.876 and 0.844, respectively.

In terms of relative error coefficient RE, Tank, Simhyd and Sacramento models all meet the requirements. Among them, the Tank model has the best performance, with a RE of only 1.477% in the verification period. It can be seen from the table that the review period of AWBM model exceeds 10%, while its performance is better in the verification period of NSE.

3.2. Analysis of runoff simulation effect

Figure 2 is a scatter diagram of the four models representing the relationship between the calculated and observed flows, and Figure 3 shows the simulation results of the four models on the monthly average flow process from 1998 to 2002.
Figure 2. Running results of calibration and verification by AWBM, Sacramento, SIMHYD and TANK models (Note: ● for calibration; ♦ for verification)

It can be seen from Figure 2 that the calculated and observed values of the four models are all close to the 1:1 line in scatter distribution. When the runoff value is small, most of the scattered points are distributed below the 1:1 line, indicating that the calculated value is basically smaller than the observed value, especially the SIMHYD model. When the runoff value is medium, the scattered points of the four models are more evenly distributed near the 1:1 line. When the runoff value is large, the SIMHYD model is still basically distributed below the 1:1 line, while the TANK model is close to the 1:1 line, showing a better performance. The prediction results of the model deviate, which is mainly because the centralized hydrological model assumes the consistency of underlying surface, neglects the uneven spatial and temporal distribution of runoff production and the process of river confluence, and only reflects the average effect of each influencing factor on runoff formation.

Figure 3. Observed and simulated average monthly streamflow by AWBM, Sacramento, SIMHYD and TANK models in 1998-2002.
Through the analysis of Figure 3, it can be seen that the AWBM model has a poor simulation effect in the flood rise period, but has a better simulation effect in the flood season and flood fall period. The overall distribution of the TANK model and Sacramento model is very close to that of the AWBM model, but both the deviation between the calculated value and the observed value in July reaches 33.80% and 27.88% respectively. From the perspective of the whole runoff process, the calculated discharge of the four models in the dry season is obviously lower than the observed value, and the fitting effect is poor, which is the same as the analysis results in Figure 2. The runoff simulated by AWBM model, Tank model and Sacramento model is generally small compared with the observed value. The calculated runoff value of SIMHYD model is generally larger in flood season.

4. Discussion
In this paper, four models are used to simulate runoff with Nash efficiency coefficient as the objective function. As can be seen from Figure 2 and Figure 3, the simulation performance of the four models for runoff in the dry season is poor. Believed that because the difference between the observed flow and the calculated flow in the Nash coefficient calculation formula was in the form of square, the Nash coefficient would be too sensitive to the flood peak. Therefore, when the Nash coefficient was used as the objective function for parameter rate, the simulation effect of flood flow was more likely to be satisfied.

In this paper, it is believed that the main reason for the large difference in Sacramento rate performance between calibration and verification periods is that the model has more parameters, which can always achieve better simulation effect by adjusting parameters during periodic rate period, but at the same time, it means that the phenomenon of "equifinality for different parameters" is more likely to occur, so that the performance of parameters that conform to periodic rate flood characteristics is poor during the verification period. In comparison, the SIMHYD model considers both the charging mechanism and the superpermeability mechanism, and has a simple structure, few parameters, low data requirements and good adaptability.

5. Conclusion
In this paper, the Wujiang River Basin is taken as the study area, and four lumping hydrological models, namely AWBM, Sacramento, Tank and SIMHYD, are applied to simulate the runoff process.

1) According to the calibration results of the models, both the Nash-Sutcliffe efficiency coefficient and relative error of the SIMHYD model and the Sacramento model meet the requirements, and the Nash-Sutcliffe efficiency coefficient and relative error of the SIMHYD model are better than the Sacramento model in general.

2) According to the simulation results of each model on the monthly average discharge process from 1998 to 2002, the AWBM model has a poor simulation effect on the runoff during flood rise period, but a better simulation result on the runoff during flood fall period. The simulated values of the four models in flood season are generally large, while the simulated values of runoff in dry season are generally small.

3) From the perspective of model structure, AWBM model, Sacramento model and SIMHYD model, except Tank model, all consider two mechanisms of runoff generation, namely overpermeability and full storage, and the physical meanings of the three model parameters are clear. However, Sacramento model has a large number of parameters, with 17 flow-producing parts, some of which are not independent, and there is an obvious phenomenon of "equifinality for different parameters", which brings some difficulties to parameter debugging.

Acknowledgement
Funding from Research on the Application of Real-time Flood Forecasting in Wujiang River Basin project of the Innovation and Entrepreneurship Training Program for 2020 College Students of Southwest University (Project No. is X202010635340).
References

[1] Weingartner, R., Barben, M., Spreafico, M. (2003) Floods in mountain areas-an overview based on example from Switzerland. J. Hydrol, 282:10-24.

[2] Xiong, J.H., Tang, C.Y., Tong, B., et al. (2020) Flood dispatching and forecasting model for cascade reservoirs in Wujiang River Basin. Yangtze River, 51: 87-91.

[3] Zhang, J.Y. (2010) Review and reflection on China's hydrological forecasting techniques. Adv. Water. Sci, 21: 435-443.

[4] Xiong, J.H., Guo, L.J., Tong, B., et al. (2011) Analysis on flood forecasting method of Wujiang River Basin affected by hydropower projects. Yangtze River, 42: 35-37.

[5] He, R.M., Wang, G.Q., Zhang, J.Y., et al. (2007) Impacts of Environmental Change on Runoff in the Yiluohe River Basin of the Middle Yellow River. Research of Soil and Water Conservation,14: 297-301.

[6] Yao, C. (2014) Improving the flood prediction capability of the Xinanjiang Model in ungauged nested catchments by coupling it with the geomorphologic instantaneous unit hydrograph. J. Hydrol,51:1035-1048.

[7] Wu, X.F., Liu, C.M. (2002) Progress in Watershed Hydrological Models. Progress in Geography, 21: 341-347.

[8] Li, Z.Y., Xie, P.C., Du, P.F. (2021) Analysis of equifinality for different parameters in water quality modeling of SWMM. Water & Wastewater Engineering, 57: 133-139.