Simulation of rainfall runoff based on flood season stage

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Abstract. The staging simulation model is based on the flood season staging, which considering the weather system genesis and rainstorm characteristics. Moreover, the physical mechanism of rainfall runoff can be comprehensively considered, and the physical meaning of the parameter can be better reflected in different stages. In this paper, the Tingxia basins in the humid and semi-humid areas are selected, which the flood season can be divided into in plum rains period and the typhoon period, then the staged simulation model is constructed by the staged rate. Some statistical indicators are introduced to evaluate the effectiveness of the staging rainfall-runoff model in improving simulation accuracy, the simulation results are ideal, and the accuracy is improved.

1. Introduction
Due to the complex and variable factors of runoff formation, the hydrological model is often generalized in the process of establishing the runoff, and its structure only reflects the main process of runoff formation. At the same time, after the model structure is determined, the influence of the model parameters on the runoff is very important. Under the same rainfall input condition, different parameters produce different runoff output. Although the parameters have clear physical meaning, they are not directly measurable at present, and can only be determined by system identification, parameter estimation and preferred methods. The parameters not only reflect the characteristics of the underlying surface of the basin, but also are closely related to the meteorological and hydrological conditions of the basin. The parameters are subject to the external conditions of the basin [1-2]. For watersheds with different hydrological characteristics, the parameters must be different. Even in the same watershed, the same rainfall, different rainfall intensity, rain type, duration and different initial soil water conditions will lead to different characteristics of the production and convergence, which will make the model parameters different.

In the past, most of the basin flood forecasting based on historical hydrological data, through the determination of the parameters of the basin hydrological forecasting model, based on the normative requirements, using the general forecast results of most floods as a criterion, seeking a general or averaging law for the formation of runoff in the basin [3]. This homogenization tends to weaken the physical meaning of the model parameters and the time-varying characteristics of the parameters, resulting in a better fit of the model to the general flood and a poor fit to the atypical flood [4-5]. Therefore, the external conditions affecting the parameter values are summarized, the optimal values of the parameters under specific conditions are classified, and the model parameter database under different external conditions of the river basin is established. In the simulation forecast, the corresponding parameter values are automatically selected according to the external conditions such as different meteorological and underlying surface conditions [6], so that the model parameters initially have artificial
intelligence, which is very beneficial to further improve the simulation accuracy.

The results of the flood season staging are based on the analysis of the causes of heavy rain and the analysis of the distribution of rainstorm time series. Therefore, the differences and similarities of the flood schedules of different stages and the same stages are obvious. According to the results of the flood season stage study, combined with the flood characteristics in different periods of the flood season. Establishing a staged flood forecasting model can better reflect the objective reality of flood characteristics and time-course changes, and improve forecasting accuracy. Based on the results of flood season staging, this paper proposes a forecast model based on flood season staging, and introduces statistical indicators to evaluate the effectiveness of the staging forecast model in improving forecast accuracy. It realizes the organic combination of parameter classification and hydrological classification and forecasting.

2. Staged rainfall runoff simulation methodology

2.1. Theoretical basis

The flood season in Zhejiang Province is usually divided into the plum rains period and the typhoon period. It is affected by different weather systems, and the characteristics of rainstorms vary greatly, resulting in significant differences in flood characteristics during different periods. During the plum rains period, the heavy rain lasted for a long time and the intensity of the heavy rain was not large. Although the flood peaks formed by the floods were not too large, they often had a large amount of time. The heavy rains in the typhoon period generally had a large concentration of rainfall, and often formed a flood with a high flood peak. And it is extremely easy to cause disasters. The difference in the regularity of these floods makes the water source division and the convergence process and other related parameters in the model greatly different. In the early stage, the soil water content can be derived from the daily precipitation evaporation information, and the model is derived from the water balance principle analysis. These values reflect the dry and wet conditions of the previous soil, affecting the relevant parameters such as impervious area and flow-to-flow ratio. The location of the rainstorm center can be determined by the location analysis of the automatic rain gauge station in the basin, and is divided into several grades according to the distance from the exit section of the rainfall station and the ratio of the river channel. The farther the general rainstorm center is, the smaller the river channel is, the longer the convergence time is, and the longer the flood peak lag time is, and vice versa. The analysis of rain intensity, rain type and duration is mainly to analyze the impact of storm type on runoff formation process. Normally, when the storm center moves from the upstream to the downstream, the superposition of the flood peaks will increase the flood peak flow; while the storm center moves from the downstream to the upstream, the flood peaks are flattened and the flood peak flow is weakened. In the current period, the soil is very dry, and the intensity of the beginning of heavy rain is very large. At this time, the proportion of surface runoff in the runoff formed will be significantly increased, which will inevitably affect the relevant parameters such as the water source in the model. In addition, the process of runoff formation is complicated, and the influence of various factors on the process of production and flow is also intertwined. Therefore, on the basis of single factor statistical analysis, the effects of these factors on the model parameters are comprehensively analyzed. The external conditions are similar. According to the plum rains period and the typhoon period, the floods are classified, and the model parameters and the outside world are determined respectively.

Based on the above-mentioned analysis of the model parameter values at different stage, a staging simulation model can be established. In the forecasting process, according to the subordinate time period of the flood occurrence, the sub-stage is judged and the corresponding parameters are called to improve the fitting precision of the atypical flood.

2.2. Model and parameters

The Xin'anjiang model is a hydrological model proposed by Hohai University. The model is a semi distributed model that can be used for humid and semi-humid regions. It divides the whole basin into
many blocks of unit basins, and calculates the output and convergence of each unit basin, and obtains the outlet flow process of the unit basins. Then make the calculation of the river flow concentration and get the flow for the outlet of the basin. The model calculates the evapotranspiration according to the three-layer evapotranspiration model, calculates the total runoff produced by rainfall according to the concept of full-scale production flow, and uses the basin water storage curve to consider the influence of the inhomogeneity of underlying surface. In terms of runoff composition, the total runoff is divided into saturated surface runoff, soil water runoff, and groundwater runoff. In terms of convergence calculations, the unit hydrograph is generally adopted for the surface runoff confluence of the unit area, and the linear reservoir method is adopted for the confluence of interflow and ground flow. River network convergence commonly used Muskingum method or lags and route method algorithm.

| Parameter | Physical meaning |
|-----------|------------------|
| $K$       | The conversion coefficient of water surface evaporation |
| $UM (mm)$ | The capacity of the tension water in upper layer |
| $LM (mm)$ | The capacity of the tension water in lower layer |
| $C$       | The conversion coefficient of evaporation in the deep layer |
| $WM(mm)$  | The tension water capacity of the whole layer |
| $B$       | The power of the tension water capacity curve |
| $SM (mm)$ | The capacity of the free water in surface layer |
| $Ex$      | The power of the surface free water capacity curve |
| $KG$      | Outflow coefficient of groundwater from surface free water |
| $KI$      | Outflow coefficient of interflow from surface free water |
| $KKG$     | The dissipation factor of groundwater. |
| $KKI$     | The dissipation factor of interflow. |
| $Ke$      | The parameters reflect flood wave transposition action |
| $Xe$      | The parameters reflect flood wave attenuation action |

3. Study case

3.1. Study basin and data

The staged rainfall runoff simulation methodology linked to the XAJ model is applied at a humid watershed - Tingxia, which is located in the southeast of Zhejiang Province of China, with a basin area of 176 km². It belongs to the typical subtropical monsoon climate zone. The annual average precipitation in the basin is 1500.7 mm. The precipitation between April and October is 70% to 80% in the whole year, and the other 5 months account for 20% to 30%. In this study, from 1988 to 2000, the hydro-meteorological data, such as hourly precipitation, discharge and daily evaporation, were used for calibration. Hydro-meteorological data are used to determine the optimized parameters of hydrological model, including hourly rainfall and runoff and the rate of daily evaporation. The discharge is calculated based on the change in the water level of the reservoirs. The rainfall data is obtained from rain gauges near the dams. The daily evaporation data is obtained by using daily evaporation pan data from the nearly evaporation station.

3.2. The characteristic of flood season stage in Tingxia basin

According to the basic elements of hydrological rainfall and the basic elements of flood, this paper selects 7 characteristic indexes of flood season stage, such as the precipitation, the maximum rainfall intensity, the average rain intensity, the rainfall duration, the rising flow, the flood peak flow, and the runoff depth. The statistical results for the the plum rains period and the typhoon period in the Tingxia Basin are shown in Table 2.
The rainfall–runoff characteristic of the plum rains period and the typhoon period in the Tingxia Basin can be seen from Table 2. During the plum rains period, the total amount of rainfall is not large, and the rainfall is not strong, but the rainfall lasts for a long time. The rainstorm center with 75% flood is located in the middle and upper reaches, which is affected by the regulation of the watershed. The attenuation actions of flood peak is more obvious. The flood peak flow and discharge of outlet are small. While, during the typhoon period, the rainfall duration is shorter than that of the plum rains period, but the rain intensity is strong, and the total amount of rainfall is large, almost rainstorm center are located in downstream. The confluence time is short and the reservoir adjustment effect is small. It is easy to form a flood with a large peak in outlet.

### 3.3. The model parameters for flood season stage

According to the characteristic of flood season stage in Tingxia basin analysed in previous section, the parameters of XAJ model are calibrated in the plum rains period and the typhoon period. The results are showed in Table 3.

| Table 2 | The rainfall-runoff characteristic of flood season stage |
| --- | --- |
| Stage | Flood code | Precipitation (mm) | Maximum rainfall intensity (mm/h) | Average rain intensity (mm/h) | Rainfall duration (h) | Rising flow (m³/s) | Peak flow (m³/s) | Runoff depth (mm) |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| The plum rains period | 31010623 | 45.3 | 24 | 0.93 | 8 | 13.9 | 118 | 48.83932 |
| | 31000709 | 82.8 | 41 | 1.73 | 15 | 2.2 | 153.5 | 36.86727 |
| | 31970707 | 261.2 | 29 | 1.81 | 70 | 7 | 200.5 | 223.831 |
| | 31950702 | 74.8 | 25 | 1.56 | 17 | 8.3 | 126.5 | 39.56318 |
| | 31950428 | 67 | 18 | 1.4 | 18 | 25.9 | 136.2 | 55.15158 |
| | 31930703 | 75.7 | 9 | 1.05 | 30 | 13 | 115 | 83.74091 |
| | 31900623 | 109 | 17.8 | 1.73 | 33 | 6 | 189 | 64.39706 |
| | 31900614 | 67.8 | 54.7 | 1.23 | 20 | 5 | 104 | 40.79456 |
| | 31890701 | 102 | 12.2 | 0.85 | 74 | 6.7 | 157 | 94.73523 |
| | 31890521 | 89.7 | 10.6 | 1.06 | 42 | 6.6 | 117 | 70.09773 |
| | 31890412 | 67.1 | 6.7 | 1.12 | 28 | 8 | 109 | 50.67204 |
| | 31880617 | 143.7 | 9.3 | 1.34 | 70 | 5.6 | 173 | 125.0346 |
| Average | 98.04 | 21.44 | 1.32 | 35.42 | 9.02 | 141.56 | 77.81 |
| The typhoon period | 31000913 | 86.8 | 11 | 1.21 | 32 | 2.1 | 104 | 52.73795 |
| | 31000829 | 104.5 | 21 | 1.45 | 28 | 13.9 | 184.2 | 101.9598 |
| | 31970816 | 191.8 | 49 | 2 | 21 | 6.8 | 824.5 | 205.9507 |
| | 31940821 | 144.8 | 45 | 3.08 | 17 | 7 | 493.3 | 100.3766 |
| | 31920022 | 204 | 58 | 3 | 29 | 6 | 1101 | 183.7534 |
| Average | 189.79 | 35.42 | 2.71 | 34.57 | 7.46 | 608.29 | 159.22 |

The rainfall–runoff characteristic of the plum rains period and the typhoon period in the Tingxia basin can be seen from Table 2. During the plum rains period, the total amount of rainfall is not large, and the rainfall is not strong, but the rainfall lasts for a long time. The rainstorm center with 75% flood is located in the middle and upper reaches, which is affected by the regulation of the watershed. The attenuation actions of flood peak is more obvious. The flood peak flow and discharge of outlet are small. While, during the typhoon period, the rainfall duration is shorter than that of the plum rains period, but the rain intensity is strong, and the total amount of rainfall is large, almost rainstorm center are located in downstream. The confluence time is short and the reservoir adjustment effect is small. It is easy to form a flood with a large peak in outlet.

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| Table 3 | The model parameters for flood season stage |
| --- | --- |
| Parameter | K | WM | WUM | WL | B | C | SM | EX | KI | KG | CS | CI | CG | K | XE |
| Unstage | 0.5 | 150 | 20 | 80 | 0.2 | 0.16 | 15 | 1.5 | 0.35 | 0.35 | 0.3 | 0.88 | 0.9 | 1 | 0.38 |
| The plum rains period | 0.5 | 150 | 20 | 80 | 0.2 | 0.16 | 20 | 1.5 | 0.35 | 0.35 | **0.45** | **0.8** | 0.9 | 1.2 | 0.38 |
| The typhoon period | 0.5 | 150 | 20 | 80 | 0.2 | 0.16 | 10 | 1.5 | 0.35 | 0.35 | **0.25** | **0.8** | 0.9 | 0.8 | **0.35** |
4. Results and discussion

In order to evaluate the goodness of the model performance produced by the methodology, four evaluation criteria are used, such as the bias of model performance in percentage ($\Delta R$), the simulation capability of peak flow ($\Delta Q$), the measurement of fit-goodness to compare the performance of the model with the observed flow (DC), the proportion of qualified floods (QR). They are expressed as:

$$
\Delta R(\%) = \left( \frac{(R_{cal} - R_{obs})}{R_{obs}} \right) \times 100% 
$$

$$
\Delta Q_m(\%) = \left( \frac{(Q_{mcal} - Q_{mob})}{Q_{mob}} \right) \times 100% 
$$

$$
DC = 1 - \frac{\sum_{t=1}^{n} (Q_{t-cal} - Q_{t-obs})^2}{\sum_{t=1}^{n} (Q_{t-obs} - \bar{Q}_{obs})^2} 
$$

$$
QR = \frac{n}{m} \times 100% 
$$

Where: $R_{obs}$ and $R_{cal}$ represent the observed and computed runoff; $Q_{mob}$ is the observed peak storage, $Q_{mcal}$ is the calculated peak storage, $Q_{t-obs}$ the observed flow at t, $Q_{t-cal}$ the calculated flow at t, $\bar{Q}_{obs}$ is the average value of observed flow, $n$ stands for the number of the qualified floods, $m$ is the number of floods used for calibration.

In Table 4, the model performances of the staged rainfall runoff simulation methodology for flows in Tingxia basin are given.

| Stage               | $\Delta R(\%)$ | $\Delta Q_m(\%)$ | DC    | QR (%) |
|---------------------|----------------|------------------|-------|--------|
| Unstage             | 7.88           | 6.75             | 0.78  | 86     |
| The plum rains period | 7.41           | 6.06             | 0.79  | 92     |
| The typhoon period  | 5.86           | 6.30             | 0.81  | 93     |

The conclusion to be drawn from the Table 4 is that:

1. For the plum rains period, the deterministic coefficient and the runoff depth error are not significantly improved. This is mainly because the parameter simulation accuracy before the unstaged period is already good. After the stage adjustment, the parameters are adjusted to reduce the flood peak error. At the same time, due to the correlation of the model parameters, some field floods will be caused. The flood volume (that is, the runoff depth) shows an increase in error, but from the final result, the runoff depth error after the stage is still much smaller than the allowable runoff depth of 20% of the measured runoff specified by the forecast specification; and other evaluation indicators such as the flood peak relative error from 6.75% decreased to 6.06%, and the flood pass rate increased from 86% to 92%; overall, the simulation accuracy of the model was improved.

2. For the typhoon period, the simulation accuracy has been significantly improved, especially the relative error of flood peak and flood volume. This is mainly due to the impact of floods in the plum rains period when the parameters are not staged, which makes the flood peaks of the flood season large during the typhoon period. By properly adjusting the water source and the convergence parameters, the simulation accuracy of flood peak and runoff depth is significantly improved, and the pass rate of flood simulation is also increased from 86% to 93%.

Moreover, in order to more intuitively display the influence of the staging parameters on the flood simulation, the flood process of the two floods in pre and post flood season stage are selected for analysis, that is flood 31890412 in in plum rains period, and flood 31920922 in typhoon period (see in Fig. 1).
Seen from Fig. 1, the unstaged parameters often lead to the pre-expansion time of the simulated flood peaks in the plum rains period, and the flood peaks are larger, while the simulated flood peaks in the typhoon period are later, and the flood peaks are smaller. This is mainly because, during the non-staged period, the SM that controls the proportion of water source, the regression coefficients CS, CI, CG and the channel propagation time KE of each water source cannot better reflect the different storm and flood characteristics of the plum rains period and the typhoon period. Therefore, when staged rainfall runoff simulation methodology is used, the flood season is divided into plum rains period and typhoon period, the SM is appropriately increased in the plum rains period, the surface water regression coefficient CS and the river propagation time KE are increased, and the surface water regression coefficient CS and the river propagation time KE are reduced during the typhoon period, so that the staged parameters can be effectively feedback from different stages of storm flood characteristics, the simulation accuracy is significantly improved from the peak, flood and peak time.

5. Conclusion
The natural geographical factors of the underlying surface of the soil, vegetation and river system in the basin are generally not changed in a short period of time, the differences in the characteristics of flood and sediment flow in each flood, which in turn affects the causes of changes in the parameters of the model, mainly caused by the meteorological factors and soil water in the basin. According to these external conditions, different parameter values are selected for different characteristic floods, which is one of the effective ways to improve the accuracy of model simulation.

In this paper, the Xin'anjiang model is applied to the Tingxia basin in the humid and semi-humid area. The flood season of the basin can be divided into the plum rains period and the typhoon period. According to the different characteristics of rainfall runoff in different stages, seven indicator factors are selected to quantitatively evaluate the floods with different stages. Meanwhile, different model parameters are chosen for rainfall runoff simulation, the results show that the flood peak relative error from 6.75% decreased to 6.06%, and the flood pass rate increased from 86% to 92%; overall, the simulation accuracy of the model is improved in the plum rains period, and for the typhoon period, the simulation accuracy of flood peak and runoff depth is significantly improved, and the pass rate of flood simulation is also increased from 86% to 93%.

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