Application of Synthetic Unit Hydrograph on HEC-HMS Model for Flood Forecasting

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Abstract: The surface runoff model of the HEC-HMS hydrological modeling system is mainly simulated through the unit line method. The simulated results usually had big errors because of the flood with different net rainfall magnitude using the same set of unit lines. In this paper, the Huan River Basin was selected as the study area for the flood forecasting using HEC-HMS model. In the process of the HEC-HMS hydrological model construction, the ArcGIS software was used to extract the watershed information according to the river DEM data. The net rainfall was calculated through the initial constant rate loss model. The surface runoff of the basin was calculated by the Snyder unit line model, and the basis was calculated by the exponential decay model. The river flow convergence was calculated by the Muskingum method. Based on the rainfall runoff data of 17 floods, three sets of Snyder unit lines were calculated according to the net rainfall intensity, and then three large, medium and small floods were employed to verify the flow process of the exit section of the basin. The model was calibrated and verified using historical observed data. The results showed that: The determination coefficients and coefficients of agreement for all the flood events were above 0.92, and the relative errors in peak discharges were all within the acceptable range, which belongs to A-Level forecast. The simulation accuracy of the model in the Huan River basin can be enhanced by synthesizing the Snyder unit line in the HEC-HMS model according to the net rain intensity.

1 Introduction

The HEC-HMS model is a hydrological simulation system that was developed by the US Army Engineering Corps Hydrology Engineering Center^[1], which is a semi-distributed hydrological model with physical concepts^[2]. The model considers the uneven distribution of rainfall and underlying surface distribution, which offers a variety of flow generation, direct runoff, base flow, and convergence calculation methods and which are convenient to apply. So far, when applying the HEC-HMS model to calculate the direct runoff convergence of the ground, the unit line method is often applied. When floods of various net rainfall intensities are predicted, the same set of parameters are used, which existing big error. In this paper, the unit line is applied to obtain the unit line with different net rainfall intensity. When the flood forecasting is carried out, the unit direct line runoff calculation is selected in accordance with the net rain intensity to improve the accuracy of the confluence forecast^[3]. Meanwhile, when applying the HEC-HMS model to sub-

basin, the method of natural watershed is often adopted, which often needs to divide many sub-basins. Thereby, to increase the computational workload. This paper intends to use the Thiessen polygon method to divide the sub-basin and to carry out the calculation of runoff yield so that computational efficiency can be improved^[4,5].

2 Research area and data sources

2.1 Overview of the research area

The Huan river is located in the north of the Yangtze River in Hubei Province, at the southern foot of the Dabie Mountains, in Xiaogan City area in the North of Jiangnan Plain. The watershed boundary lies between longitude 113°72' and 114°33' and latitude 30°86' and 31°89'. The main stream is 8 km, and the drainage area is 2590.88km². Watershed topography is high in northeast and low in southwest. The landform is mainly hilly and mountainous. The northeast is a low mountain area with the height from 500m to 1000m and low hills in the

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southwest with the height from 100m to 500m. The basin is a subtropical monsoon climate with abundant rainfall, with annual precipitation ranging from 1040 mm to 1230 mm. 70% precipitation is concentrated in April to 9 September. The largest flood measured in history is in July

17, 1996, with peak flow of 6060 m^3/s and s 39.95 m flood-peak stage. The elevation map of the river basin is shown in Fig. 1.

Fig.1 Huan River Basin elevation map

2.2 Basic data

The research data of the basin includes: Using the 1:100,000-scale land use status remote sensing monitoring data provided by the Resource and Environmental Science Data Center of the Chinese Academy of Sciences, sing the Hydrological Yearbook to find rainfall runoff data for seven rainfall stations from 1969 to 1989 and evaporation data, NASA provided 90m SRTM digital elevation data.

3 Research methods

3.1 Establishment of watershed models

In this paper, the basin background map was generated by GIS, and the basin was divided into 7 sub-basins by Tyson polygon method. The hydrological units such as the sub-basin, river and confluence point were added to the basin background map, and the watershed model map was established as shown in Fig.2. The sub-basin area was shown in Table 1.

Fig.2 Schematic diagram of the HEC-HMS

Table 1 Sub-basin area and weight

Sub basin	Area (Km^2)	Weights
A	259.96	10.03
B	269.74	10.41
C	272.75	10.53
D	464.89	17.94
E	410.06	15.83
F	433.36	16.73
G	480.12	18.53
The total area	2590.88	1

3.2 Computational model of runoff volume

The initial constant rate loss method was employed to simulate the runoff process. The initial constant rate loss method means that the maximum potential rainfall loss f_c constant throughout the rainfall process.

The net rainfall pe_t this period was given by formula 1.

$$pe_t = \begin{cases} 0 & \text{If } \sum P_i < I_a \\ P_t - f_c & \text{If } \sum P_i > I_a \text{ and } P_t > f_c \\ 0 & \text{If } \sum P_i > I_a \text{ and } P_t < f_c \end{cases} \quad (1)$$

In the formula: $\sum P_i$ is the cumulative rainfall; P_t is the rainfall intensity

To indicate interception and pothole filling, the constant I_a added to the initial loss. Water interception is a part of rainfall interception in catchment area, including vegetation. Filling water is the loss of rainfall caused by the change of the topography of catchment area. The sum of these two parts is the initial loss, which occurred before the surface runoff.

3.3 Surface runoff model

In this paper, the Snyder unit line model was applied to simulate the surface runoff process of clear rain in catchment area^[6]. The peak flow delay, peak flow and total time datum were selected as the eigenvalues of unit line for the model. Among them, the relation between rainfall duration and peak flow latency, as shown in formula (2).

$$t_p = 5.5t_r \quad (2)$$

In the formula: t_r is the rainfall duration; t_p is peak flow latency

Delay per unit line of precipitation per unit area and the peak value of unit line in unit area can be associated with the following formula (3)

$$\frac{U_p}{A} = C \frac{C_p}{t_p} \quad (3)$$

In the formula: U_p is the peak value of the standard unit line; A is the drainage area of the catchment; C_p is peak coefficient of unit line. C is the conversion constant (the unit system for SI is 2.75 and the unit system for a pound of feet is 640).

In the model, the peak flow latency t_p and the peak coefficient of unit line C_p were needed to be determined. Because the unit line of different rain intensity had peak flow latency, in order to improve the accuracy of forecast, in this paper, the method of classification and synthesis was used to set the parameters according to the magnitude of rain intensity.

3.4 Base flow model

The exponential decay model was employed to calculate the base flow of secondary flood. The model was generally used to describe the natural drainage process of watershed water storage. Base flow Q_t Defined at the t time of this model was shown in formula (4).

$$Q_t = Q_0 k^t \quad (4)$$

In the formula: Q_0 is the initial discharge; k is the exponential recession constant.

3.5 River flow model

Muskinggen method was applied in the calculation of river confluence^[7]. The calculation formula of the method as follows:

$$Q_t = \frac{\Delta t - 2KX}{2K(1-X) + \Delta t} I_t + \frac{\Delta t + 2KX}{2K(1-X) + \Delta t} I_{t-1} + \frac{2K(1-X) - \Delta t}{2K(1-X) + \Delta t} Q_{t-1}$$

In the formula: Q_t is the discharge of the section at T moment; Δt is the period length of simulated rainfall runoff process of the model.

K is the travel time when the upward flow is a constant flow; X is the flow specific gravity factor. I_t is the inflow discharge of the cross section at T moment; I_{t-1} is inflow of the upper end face at $t-1$ moment; Q_{t-1} is the outflow of the lower section at $t-1$ moment;

4 Results and analysis

The parameters in the HMS model include: constant osmotic rate f_c , peak flow delayed time t_p , peak coefficient C_p , peak flow threshold, recession coefficient k , drain constant k and flow specific gravity factor x . In this paper, 21 floods from 1969 to 1989 were used for the analysis of watershed runoff, taking 19 floods as the parameter rate of HMS model. The model was calibrated and verified using the other three historical flood, the model suitable parameters for the river basin were obtained. The results were shown in Table 6-10. In this paper, the influence of different net rainfall on Snyder unit line was considered for rainfall runoff relation in Huan river base, the net rainfall was divided into three groups and each group was corresponding to a peak flow latency. The accuracy of the regular simulation of the model rate was shown in Table 11. The accuracy of the prediction for the verification period was shown in Table 12. The predicted flow duration curve in the verification period was shown in Fig. 3

Table 6 Parameters of the Muskingen model

Reach	Parameters	Optimized parameter value
Reach-1	K	5.314
Reach-1	X	0.347
Reach-2	K	1.719
Reach-2	X	0.332

Reach-3	K	4.002
Reach-3	X	0.340
Reach-4	K	6.383
Reach-4	X	0.322
Reach-5	K	1.705
Reach-5	X	0.323
Reach-7	K	1.536
Reach-7	X	0.330
Reach-8	K	5.330
Reach-8	X	0.300
Reach-9	K	4.548
Reach-9	X	0.352
Reach-12	K	1.825
Reach-12	X	0.339
Reach-13	K	3.590
Reach-13	X	0.332

Table 7 Parameters of Snyder's UH

Sub basin	Parameters	Optimized parameter value
A basin	Peaking coefficient	0.220
B basin	Peaking coefficient	0.185
C basin	Peaking coefficient	0.214
D basin	Peaking coefficient	0.218
E basin	Peaking coefficient	0.225
F basin	Peaking coefficient	0.218
G basin	Peaking coefficient	0.197

Table 8 Parameters of the exponential recession model

Sub basin	Parameters	Optimized parameter value
A basin	The threshold value	0.156
A basin	Recession constant	0.492
B basin	The threshold value	0.158
B basin	Recession constant	0.478
C basin	The threshold value	0.160
C basin	Recession constant	0.483
D basin	The threshold value	0.137
D basin	Recession constant	0.490
E basin	The threshold value	0.159
E basin	Recession constant	0.499

F basin	The threshold value	0.185
F basin	Recession constant	0.490
G basin	The threshold value	0.139
G basin	Recession constant	0.467

Table 9 Initial constant rate loss model parameter optimization table

Sub-basin	Parameters	Optimized parameter average(in/h)
A basin	Constant Rate	0.228
B basin	Constant Rate	0.225

C basin	Constant Rate	0.202
D basin	Constant Rate	0.225
E basin	Constant Rate	0.199
F basin	Constant Rate	0.200
G basin	Constant Rate	0.228

Table 10 Correspondence between flood peak delay and net rainfall

Net rainfall (in)	Standard lag
(0, 2.74)	2
(2.74,3.03)	4
(3.03,+∞)	5

Table 11 Model rate determination

Number	Start and end time (year - month - day)		Runoff depth / (mm)			Flood-peak discharge / ($m^3 \cdot s^{-1}$)			Peak time/h			DC
	Starting time	End Time	Analog error	License error	Evaluate	Analog error	License error	Evaluate	Analog error	License error	Evaluate	
1	1970-5-26	1970-6-4	-25.9	18.7	F	-1593.62	528.22	F	6	3	F	0.615
2	1971-5-1	1971-5-9	-3.21	9.96	Q	5.21	116.25	Q	1	3	Q	0.974
3	1971-6-24	1971-7-7	-1.13	16.2	Q	-76.24	188.68	Q	2	3	Q	0.936
4	1972-5-11	1972-5-22	-5.16	7.04	Q	-19.17	103.83	Q	3	3	Q	0.858
5	1974-4-11	1974-4-17	9.75	3.78	F	4.8	117.2	Q	1	3	Q	0.763
6	1974-8-2	1974-8-9	1.67	5.96	Q	30.31	185.6	Q	3	3	Q	0.921
7	1975-7-8	1975-7-19	-0.75	18.3	Q	-422.83	526.22	Q	4	3	F	0.922
8	1975-10-9	1975-10-20	-1.13	8.04	Q	-33.75	126	Q	4	3	F	0.857
9	1976-7-14	1976-7-25	2.37	14.46	Q	-730.14	410	F	0	3	Q	0.674
10	1977-7-15	1977-7-25	13.44	14.71	Q	-236.82	240	Q	6	3	F	0.842
11	1982-8-17	1982-8-31	15.1	19.43	Q	-494.72	218	F	3	3	Q	0.485
12	1983-7-21	1983-7-31	-4.92	34.55	Q	-29.74	588.24	Q	0	3	Q	0.929
13	1983-9-15	1983-9-27	-4.48	11.15	Q	-243.18	274.2	Q	1	3	Q	0.932
14	1984-7-16	1984-7-27	9.47	12.73	Q	-118.98	220.09	Q	1	3	Q	0.899
15	1985-5-2	1985-5-11	8.09	13.29	Q	57.14	258	Q	0	3	Q	0.88
16	1987-4-30	1987-5-10	-0.27	13.41	Q	-6.56	399.31	Q	1	3	Q	0.91
17	1987-7-19	1987-7-27	-3.94	8.22	Q	0.7	244.2	Q	1	3	Q	0.984

Table 12 Flood forecasting results evaluation

Flood sequence	Runoff depth <i>mm</i>	Runoff depth <i>mm</i>	Relative error %
198708	32.51	33.75	-3.67
198705	79.85	72.4	-10.29
198207	75.55	78.34	-3.56

Table13 Flood peak forecasting results evaluation

Flood sequence	Simulation of flood peak m^3/s	The measured peak m^3/s	Relative error %
197105	762	751	1.46

198705 2346.96 2270 3.39

198207 699.07 725.3 1.36

Table 14 Peak time and deterministic coefficient

Flood sequence	Flood peak time error h	DC	Precision grade
197105	1	0.948	A
198705	1	0.964	A
198207	0	0.924	A

The simulation results were shown in Fig. 3.

For three different rainfalls, three different unit lines were used to simulate rainfall runoff in the basin, and the

simulation results were all A-level forecasts. The results show that HEC-HMS can better predict floods by using different unit lines in the Huan River Basin.

Fig.3 Comparison of simulated flood with measured flood

5 Conclusion

The method of Tyson polygon was used to calculate the yield and confluence of sub-watersheds, the number of sub-basins divided was less, the simulation precision can meet the requirements, and the efficiency of calculation can be improved.

In the Huan river basin, Integration of unit lines according to the size of the secondary flood clean rain could improve the accuracy of flood forecasting. The HEC-HMS model could effectively apply forecast the secondary flood in the river basin. The HEC-HMS hydrological model was suitable for hydrology simulation in the study area.

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