Hydrological Simulation of Wohushan Reservoir Basin Based on NAM Model

Jiazhen Zhao¹, Fangjing Cao², Jianguang Wang³, Taili Li⁴

¹School of Water Conservancy and Environment, Jinan University, Jinan, Shandong, 250000, China
²Shandong Province Haihe Huaihe Xiaoqing River Basin Water Conservancy Management Service Center, Jinan, Shandong, 250000, China
³Weifang Water Conservancy Architectural Design and Research Institute, Weifang, Shandong, 261000, China
⁴Water Affairs Bureau of Penglai District of Yantai City, Yantai, Shandong, 264000, China

*Corresponding author’s e-mail: 13612105009@163.com

Abstract: Based on the NAM model, a hydrological model of the Wohushan Reservoir was constructed. The rainfall and runoff processes of the Wohushan Reservoir were simulated. The model was calibrated with 6 measured floods, and the model was verified by 6 measured floods. The result showed that the qualified rate of the simulation results of the model was 83.3%, which reached the standard of the qualified rate of the model. In the flood simulation that meets the qualification requirements, the maximum error between the measured and simulated flood peaks is 14.248% and the minimum error is 10.001%; the maximum error between the measured and simulated flood peaks during the verification period is 12.376% and the minimum is 5.392%. The fitting of the measured flow process is relatively ideal and has certain practical significance.

1. Introduction
The NAM model is a lumped conceptual hydrological model, first proposed in 1973 by Nielsen and Hansen of the School of Hydrodynamic Engineering of the Technical University of Denmark [1]. The NAM model simulates the rainfall runoff process that occurs within the basin. It does not consider the spatial changes of the characteristic parameters of each part of the basin, and analyzes the entire basin as a whole. Each small basin is regarded as a unit. The variables represent the average value of each basin [2]. Since the NAM model was incorporated into MIKE11 to simulate the rainfall-runoff relationship of the sub-basin in 1995, the model has been widely used in different engineering projects [3]. In 1996, my country introduced this model for the first time and applied it to the "Heavy Rain and Flood Forecast of the Middle Yangtze River". In 2005, Yu Yougui [4] applied the NAM model to the simulation of the Mengjiang River in the Pearl River Basin, and compared the results with the simulation results of the Xin'an River model. The results showed that the simulation accuracy of the NAM model was high. In 2012, Song Yaya [5] used NAM rainfall runoff model to simulate the Shaziling watershed and conducted an effect analysis. The analysis results showed that the NAM simulation forecast effect is better. In 2015, Chen Zhiyang [6] applied the NAM model to simulate the
flood process of the Aojiang River Basin in response to the flood forecasting problem, and provided technical support for flood forecasting.

Wohushan Reservoir is the only large-scale reservoir in Jinan. Floods during the flood season will bring many inconveniences to the construction and development of Jinan. Therefore, it is very necessary to carry out rainfall and runoff forecast simulation research in this basin. In order to give full play to the flood control effect of Wohushan Reservoir, this paper constructs a hydrological model of Wohushan Reservoir basin based on the basic principles of runoff generation and convergence of the NAM model. Through calibration and verification of the model, it is found that the NAM model has a better effect on flooding in the Wohushan Reservoir basin. The high simulated longitude can provide a strong basis for flood control and dispatching of reservoirs, and can also improve the utilization rate of water resources in the basin.

2. Overview of the study area
The watershed of Wohushan Reservoir is located in the mountainous area in the southern part of Jinan City, at 116.94°~117.34°E, 36.33°~117.34°N. The drainage area of the reservoir is 553.4km², with a total storage capacity of 122 million m³. The basin is located at the northern foot of Mount Tai, at the junction of the piedmont plain between Mount Tai and the Yellow River, and belongs to the Yellow River system. The basin is composed of Jinxiuchuan, Jinyangchuan and Jinyunchuan basins. The three rivers flow into Wohushan Reservoir. After flowing out of the reservoir, they form the Yufu River, the largest river in the basin. The Yufu River is 95.7km in length and flows northward into Dangjia Town. Within the territory, it flows from Fengqi area to Gucheng Village and turns south to Beidianzi Village to the northwest and flows into the Yellow River. The terrain of the entire basin is high in the south and low in the north, high in the east and low in the west. It is a continental monsoon climate in a warm temperate semi-humid zone. The watershed map of Wohushan Reservoir is shown in Figure 1.

3. Construction of hydrological model of Wohushan Reservoir based on NAM model

3.1. Data source and processing
Treatment of hydrological parameters of the basin. Based on the 1:100,000 topographic map of the
Wohushan Reservoir basin, the contours and elevation data are extracted based on ArcGIS 10.2, and the vectorization and projection changes are carried out, and they are converted into an irregular triangulated network model. The horizontal raster resolution is 10m DEM. According to the 10m×10m DEM of the Wohushan Watershed, extract river network, sub-catchment area, watershed area, river gradient and other information; and through the merger and segmentation of the natural watershed, the Wohushan Watershed is divided into 38 sub-basins (Figure 1).

3.2. Model building
According to the underlying surface conditions of the Wohushan Reservoir basin and the basin calculation unit, a basin hydrological model is established based on the NAM model, which is mainly divided into three modules: runoff generation, confluence and evapotranspiration. The NAM model is divided into four layers of water storage bodies for the simulation calculation of watershed flow generation. Through continuous calculation of the four different and mutually influencing storages of snow storage layer, surface storage layer, soil or plant root zone storage layer, and groundwater storage layer The water content of the water layer is used to simulate the process of runoff generation and convergence [6]. Since the snowfall in the Wohushan Reservoir basin has no effect on the flood, the snow storage layer is not considered.

4. Result analysis
4.1. Parameter calibration results
Using the Tyson polygon method and using ARCGIS to calculate the area weight of multiple rainfall stations in the Wohushan River Basin, the rainfall, evaporation, and measured flow of the events are input according to the different proportions of the rainfall stations in the model. According to the rainfall and flood data corresponding to the 19850729, 19640727, 19940629, 19980729, 20000809, 2005092 floods, the established Wohushan Reservoir basin hydrological model was used to perform flood simulation, the model was calibrated, and the simulation effect calibration process was adopted. The SCE algorithm automatically calibrates the parameters of the NAM model, and fine-tunes the model parameters manually. The model parameters after calibration are shown in Table 1.

| $U_{\text{max}}$ /mm | $L_{\text{max}}$ /mm | CQOF | CKIF /hr | CKI2 /hr | TOF | TIF | TG | CKnF /hr |
|-----------------------|-----------------------|------|----------|----------|-----|-----|----|----------|
| 10.002 | 100.1698 | 0.9996 | 203.26 | 11.3744 | 0.9579 | 0.2057 | 0.984 | 2142.8192 |

The simulated effects of the above 6 floods using the calibrated model parameters are shown in Figure 2 (due to the space effect, take Figure 2 as an example).
Figure 2. The simulation and calibration results of the secondary flood runoff process (19640727)

It can be seen from the simulation results that the maximum error between the measured flood peak and the simulated flood peak is 24.816%, the minimum is 10.001%, and the maximum time difference between peak currents is 6h. Except for the two unqualified (relative error greater than 20% is unqualified) of the 6 regular floods, the remaining 4 flood simulated and measured flow processes are in good agreement in peak and phase. The model structure can better reflect the hydrological and physical process of the region. The periodic result analysis of the model rate is shown in Table 2.

| Floods      | Start   | End     | Appearance of peak/h | Peak of flood (m$^3$/s) deviation % | Eligibility |
|-------------|---------|---------|---------------------|-------------------------------------|-------------|
| 19640727    | 07-22   | 07-31   | 0                   | 1020.44                             | 918.39      | yes          |
| 19850729    | 07-28   | 08-01   | 0.5                 | 571.89                              | 653.37      | yes          |
| 19940629    | 06-26   | 07-01   | 2                   | 326.11                              | 396.54      | no           |
| 19980729    | 07-26   | 07-31   | 6                   | 279.98                              | 349.46      | no           |
| 20000809    | 08-08   | 08-12   | 1                   | 453.06                              | 507.07      | yes          |
| 20050920    | 09-15   | 09-23   | 0.2                 | 320.19                              | 352.27      | yes          |

4.2. Model verification results

The calibrated model parameters were used to simulate and verify the six floods of 19940807, 19980704, 19960730, 20040715, 20080819, 20130715. The results of the verification period are shown in Table 3, and the simulated flood process is shown in Figure 3 (due to limited space, take Figure 3 as an example).

| Floods      | Start   | End     | Appearance of peak/h | Peak of flood (m$^3$/s) deviation % | Eligibility |
|-------------|---------|---------|---------------------|-------------------------------------|-------------|
| 19940807    | 08-06   | 08-15   | 1.5                 | 559.08                              | 602.34      | yes          |
It can be seen from the above simulation results that the Wohushan Reservoir watershed hydrological model based on the NAM model in this study has strong applicability in the Wohushan Reservoir watershed. Among them, the maximum error between the measured peak and the simulated peak is 12.376%, and the fitting of the simulated flow process and the measured flow process is ideal.

5. Conclusion

(1) The watershed hydrological model of Wohushan Reservoir based on the NAM model shows a good simulation effect from the simulation results. Among them, the maximum error between the measured and simulated flood peaks is 24.816%, the minimum is 10.001%, the maximum time difference between the peak currents is 6h, the maximum error between the measured and simulated peaks during the verification period is 12.376%, and the minimum is 5.392%. It can be seen that the simulation accuracy of the selected floods meets the requirements, can meet the needs of the project, and can be applied to the flood forecast model of Wohushan Reservoir.

(2) Due to the characteristics of rainstorm and topography, the average areal rainfall calculated by the Tyson polygon method sometimes cannot accurately express the rainstorm process in the basin, which affects the accuracy of the simulation to a certain extent. In addition, small-scale water conservancy projects in the basin have a certain capacity for regulation and storage. During small floods, upstream regulation and storage will affect the inflow process, often causing the simulated value to exceed the measured value. In practical applications, corresponding adjustments should be made based on experience on the premise of fully grasping the preliminary rainfall of the secondary flood and the storage conditions of upstream reservoirs.
References
[1] Fuchun, Zhangqiang. Summary of Basin Hydrological Model [J]. Jiangxi Science, 2008, 26(4): 588-638.
[2] Xie Hengyan, Yaoxuan, Zhengxin. Research Status and Prospects of NAM Model Calibration [J]. Journal of Heilongjiang Bayi Land Reclamation University, 2017, 29(05): 89-94.
[3] MADSEN H. Automatic calibration of a conceptual rain-runoff model using multiple objectives [J]. Journal of Hydrology, 2000, 235(3): 276-288.
[4] Yu Yougui. Preliminary Application Practice of NAM Model in the Pearl River Basin [J]. People's Pearl River, 2005(03): 34-37.
[5] Song Yaya, Zhu Miaoyi, Zhufujun, Gehui, Zhaojun, Huang Zhenping. Rainfall runoff model and its application [J]. Hydropower Energy Science, 2012, 30(06): 9-12+73.
[6] Chen Zhiyang, Bai Bingfeng, Zhu Yongquan, Li Haibin. Application of NAM model in flood forecasting of Aojiang River Basin [J]. Zhejiang Water Conservancy Technology, 2015, 43(01): 87-89+92.