Flood forecasting study of PanShiTou Reservoir based on three water sources Xin'an River model

Zihe Tian *, Shiyu Ji

School of Hydro Science & Engineering, Taiyuan University of Technology, Taiyuan, China, 030024

* Corresponding Author Email: eddietien@qq.com

Abstract. This paper mainly takes PanShiTou Reservoir as the research object, adopts the three water sources Xin'anjiang model to forecast and analyze the two floods of 850704 and 860520, and selects the rainfall data of six rainfall stations for these two floods, and adopts the three water sources Xin'anjiang model to carry out evapotranspiration calculations, flow production calculations, sub-source calculations, and confluence calculations to derive the predicted value of the flood, and then compare the predicted value with the actual value, and then analyze the error analysis of this study. Comparing the predicted values with the actual values and comparing the error analysis of this study, it is concluded that the prediction level of these two floods is C. This study provides an effective technical means for the flood prediction of reservoirs and provides essential support for the operation and management of reservoirs.

Keywords: Three Water Sources Xin'an River Model, PanShiTou Reservoir, Flood Forecasting.

1. Introduction

The purpose of flood forecasting is to predict the occurrence of short-, medium- and long-term river flooding and change trends; it is the basis for decision-making in flood control and rescue and flood control system scheduling and use for the rational use and protection of water resources, water conservancy projects, construction and management of the use and the safe production of industrial and agricultural production services for the average production of institutions along the river, the residents of the life and property of the safety of the water situation to provide protection, sudden large floods when the timely evacuation, can avoid many unnecessary losses [1].

PanShiTou Reservoir is located in the middle reaches of the Qi River, a tributary of the Wei River, and the dam site is near Panshi Village, about 15 km southwest of Hebi City. Panshishi Reservoir is a large-scale water conservancy hub project mainly for flood control and industrial and urban water supply, taking into account farmland irrigation combined with power generation and other comprehensive uses.

The total capacity of PanShiTou Reservoir is 679 million m^3, which is a large-scale reservoir with engineering grade 2, and its flood standard is designed for one in 100 years flood and checked for one in 2000 flood. The reservoir dead storage capacity is 20.25 million m^3, the corresponding dead water level is 207 m, the average storage level is 254 m, 282.5 million m^3, the flood control limit level is 248 m, agricultural irrigation limit level of 230 m, flood control high water level of 270 m, flood control capacity of 275.6 million m^3, of which 0.6 billion m^3 of overlap between flood control and profitability, the reservoir flood control capacity of 363 million m^3, the flood of one in 100 years. The design flood level was 270.7 m, and in the first year of 2000, the calibration flood level was 275 m.The main buildings of the PanShiTou Reservoir project are a dam, spillway, spillway, water transfer hole, and power station. Engineering grade for the second class, the main building according to the 2-level design, power station, and other buildings according to the 4-level design, seismic intensity 7 degrees. The design flood standard of the reservoir is one in 100 years, and the calibration flood standard is one in 2000 years. The design flood standard of the power station plant is one in 50 years, and the calibration flood standard is one in 100 years. The designed dam is a concrete panel rockfill dam with a crest elevation of 275.7 m, a maximum height of 102.2 m, a length of 606 m, and a width of 8 m at the crest. The spillway hole is arranged on the right bank under Cockscomb Hill.

The design flood standard of the two holes is one in 100 years, and the corresponding discharge volume is 2×1139.5 m^3/s In the case of one in 2000 calibration flood, the maximum discharge volume of the two holes is 2×1187 m^3/s. The mode of operation is the control of discharge from the spillway for one in 50 years and the following floods, the spillway for one in 50 years and the floods of one in 100 years are open to the public and the spillway for one in 100 years is used as a common discharge with the very spillway on the left bank. The very spillway is arranged at the ridge notch on the left bank outside the dam head. According to the project planning, when the reservoir encounters a one-in-a-hundred-year flood, the very spillway is activated to release flood water, and the maximum flood discharge is 6,263 m^3/s when the calibrated flood level is 275 m in the one-in-2000 year.

The primary purpose of the water transfer hole project is to provide industrial and urban water to the city of Hebi and to provide agricultural irrigation water to the four irrigation districts that have been built downstream, as well as to generate electricity in combination with water supply [2].

2. Materials and Methods/Research Methods

2.1. Data Acquisition and Preprocessing

In this paper, the rainfall, as well as measured flow and evaporation from 6 rainfall stations in 52 periods of 850704 floods starting from 8:00 p.m. on 3 July and 69 periods of 860520 floods starting from 8:00 p.m. on 19 May at PanShiTou Reservoir, are selected.

2.2. Introduction of Methods

According to the topography, geology, subsurface, hydrometeorology, and other characteristics of the PanShiTou Reservoir basin, the basin belongs to the semi-moisture area, so the three water sources Xin'an River model was selected. The Xin'an River model is a decentralized structure that divides the basin into many unit basins. The output and sink flow calculations are made for each unit basin to derive the outlet flow process of the unit basin. Then, the river flood calculation below the outlet is carried out to determine the flow process at the outlet of the basin. Adding up the outlet flow process of each unit basin, the total outlet flow process of the basin outlet is obtained. For each unit, a series of analyses, such as rainfall, evaporation, soil water content, water allocation, recession, unit river network lagging algorithm, and channel confluence, is calculated by applying the three-water source Xin'an River model [3].

The flow chart of calculation for each unit basin is shown in Figure 1. In the figure, the state variables are written inside the boxes, and the model parameters are written outside the boxes. The inputs to the model are measured rainfall P and measured water surface evaporation EM; the outputs are watershed outlet flow Q and watershed evapotranspiration E. The structure of the model and the calculation methods can be divided into evapotranspiration calculation, flow production calculation, water source calculation, and catchment calculation [4].

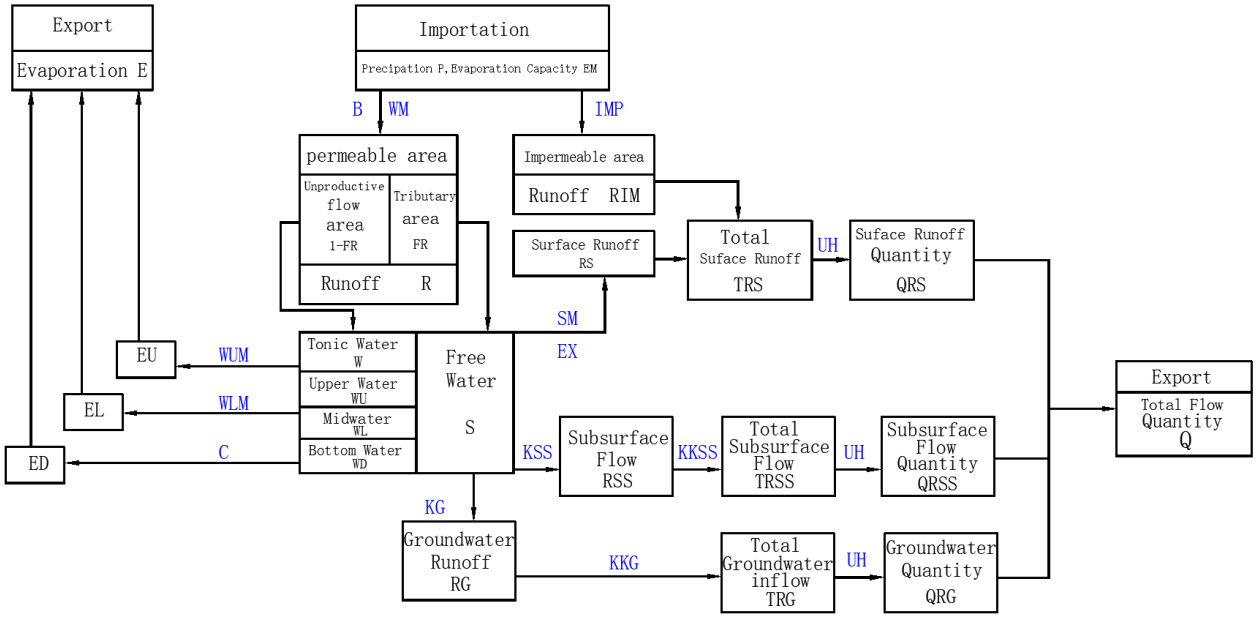


Figure 1. Flow chart of Xin'an River model with three water sources

2.3. Model Evaluation Indicators

Description of Xin'an River model parameters

(1). B is the square times of the tension water storage capacity curve, and the uneven distribution of tension water storage conditions determines this value. In general, it is related to the area of the watershed. According to the analysis of the rainfall-runoff correlation map in the hilly area, 0.1 is taken for the watershed less than 5 km2, 0.2~0.3 for several hundred to one thousand km2, and about 0.4 for several thousand km2.

(2). C is the deep evapotranspiration coefficient, which the area covered by deep-rooted plants determines, and it can reach 0.18 in the southern forested areas, while it is about 0.08 for the northern semi-humid areas.

(3). EX is the square times of the surface free water storage capacity curve. It determines the uneven distribution of surface free water storage conditions, and in hillslope hydrology, it determines the development process of the saturated slope flow production area. In view of the saturated slope flow from the foot of the slope to the slope development, the increase of the flow-producing area gradually slows down, so the EX should be greater than 1. Generally in the range of 1 ~ 1.5.

(4). IM is the percentage of impervious area in the watershed area to the total watershed area. In natural watersheds, this value is small, about 0.01 to 0.02, and may be significant in urban areas.

(5). K is the evapotranspiration capacity conversion factor. This parameter controls the total water balance, so it is important for water calculation. k=R1×R2×R3. r1 is the ratio of large water surface evaporation and evaporator evaporation, and experimental data is available for reference. r2 is the ratio of evapotranspiration capacity and large water surface evaporation, and the value is about 1.3~1.5 in the summer and about 1 in the winter. r3 is used to correct the measured value of the evaporation station to the basin average, so it mainly decides on the evapotranspiration station. R3 is used to correct the measured values of the evaporation stations to the watershed mean and is, therefore, mainly determined by the difference between the evaporation station elevation and the watershed mean elevation. When the E-601 evaporator is used, R1×R2≈1, so K is generally taken as 0.5~1.2.

(6). WM (tension water capacity) = UM + LM + DM upper, middle, and lower soil water storage capacity. That is, the basin tension water maximum water deficit, said the basin of the degree of drought. Wm in the south of China is about 100mm, and the north of the semi-moist areas is about 170mm. Um, including plant interception in the lack of forest areas, it can be taken as 5mm and more forested areas can be taken as 20mm. lm is often taken as 60~90mm. According to experiments, this range of evapotranspiration is about directly proportional to the soil moisture.

(7). SM is the free reservoir storage capacity (surface soil free water capacity); this parameter is affected by the rainfall data time homogenization; when using the day for a time long, the soil layer is a fragile area, its value is 10mm or more minor. In watersheds where the soil is deep and forested, and the water permeability is very high, the value can be up to 50mm or more, and in general, watersheds between 10 and 20mm. This parameter should be increased when the length of the period taken decreases. This parameter is decisive for the amount of surface runoff.

(8). KG is the outflow coefficient of groundwater in surface free water.

(9). KI is the outflow coefficient of surface free water in loam.

The two outflow coefficients, KG and KI, are connected in parallel, and their sum (KG+KI) represents the speed of free water outflow. For a watershed, they are constants. 1000km2 or so watershed, from the rain stop to the loam flow stop time, generally about 3d, equivalent to KG + KI = 0.7; if the recession lasts for 2d, then KG + KI = 0.8.

(10). CI is the coefficient of abatement of loamy intermediate flow. If there is no deep loam flow, CI tends to 0; when the loam flow is vibrant, CI tends to 0.9, which is equivalent to the confluence time of 10d.

(11). CG is the groundwater recession coefficient. If the length of time is a day, the value is generally 0.98~0.998, which is equivalent to the time of confluence of 50~500d.

(12). UH (river network unit line). The geomorphology of the river network determines it and is generally deduced by empirical methods.

(13). L and CS (lag time and river network storage recession coefficient in lag algorithm). The geomorphology of the river network determines them.

(14). XE and KE (two parameters of the Muskingum method). They can be deduced from the hydraulic properties of the river [5].

3. Model building and solving (results and analysis process)

3.1. Parameter values

Table.1 below shows the initial values of the parameters through the adjustment of the parameters so that the final results obtained are similar to the flow rate in the data so as to determine the parameter values of the model [6].

Table 1. Initial values of flood forecasting parameters for PanShiTou Reservoir

Parameter	Value	Parameter	Value	Parameter	Value
K	0.5~1.2	WM	160~180	WUM	20~30
IM	0.01	WLM	70~90	B	0.26~0.38
C	0.06~0.15	CG	0.25	CI	0.8~0.9
KG	0.03~0.05	KI	0.7~0.9	SM	60~80
EX	1.1~1.5	KE	1	XE	0.45
L	0	CS	0.7		

For the parameters of flood 850704 after trial calculation, the final parameter values are obtained in Table 2.

Table 2. Flood 850704 Reservoir Forecast Parameter Takes

Parameter	Value	Parameter	Value	Parameter	Value
K	1.2	WM	250	WUM	24
IM	0.01	WLM	100	B	0.4
C	1	CG	0.25	CI	0.99
KG	0.04	KI	0.05	SM	80
EX	1.1	KE	1	XE	0.45
L	0	CS	0.7		

For the parameters of flood 850506 after trial calculation, the final parameter values are obtained in Table 3.

Table 3. Flood 850506 Reservoir Forecast Parameter Takes

Parameter	Value	Parameter	Value	Parameter	Value
K	1.2	WM	230	WUM	24
IM	0.01	WLM	100	B	0.37
C	0.05	CG	0.25	CI	0.995
KG	0.035	KI	0.05	SM	70
EX	1.2	KE	1	XE	0.45
L	0	CS	0.7		

3.2. Flood forecasting results

A comparison of the results obtained from the parameters of the flood 850704 with the measured flow is shown in Figure 2. It can be seen from Figure 2 that there is a particular gap in the prediction accuracy in the early part of the forecast, and the prediction in the later part of the forecast is more similar [7].

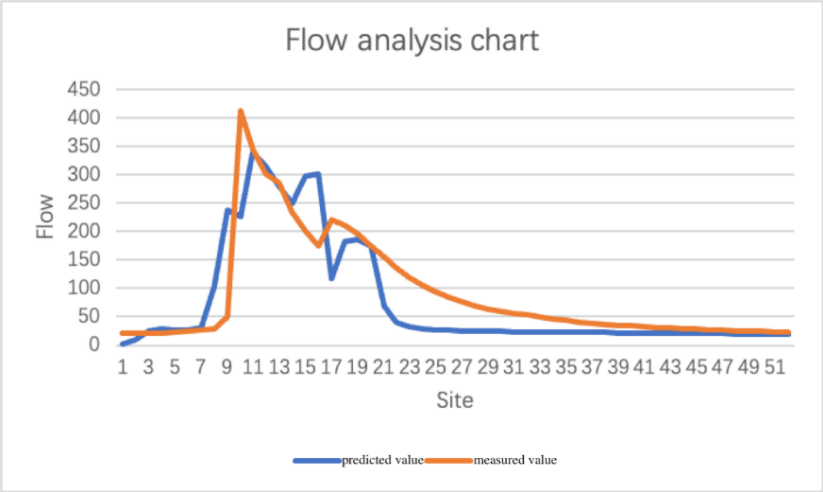


Figure 2. Comparison of measured and predicted values for flood 850704

A comparison of the results obtained from the parameters of the flood 860520 with the measured flow rate is shown below in Figure. 3. From the figure, it can be seen that the predicted values are closer to the measured values, and the series of parameters can be used to predict the flow rate of the series[8].

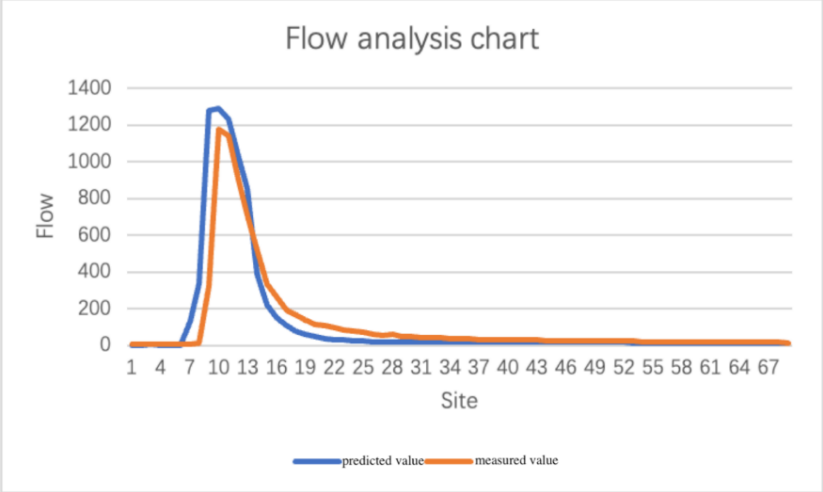


Figure 3. Comparison of measured and predicted values for flood 860520

3.3. Error analysis

According to the measured flow as well as the forecasted flow, the absolute and relative errors are calculated, and then a deterministic analysis is carried out. The specific calculation results are shown below in Figures 4 and 5 [9].

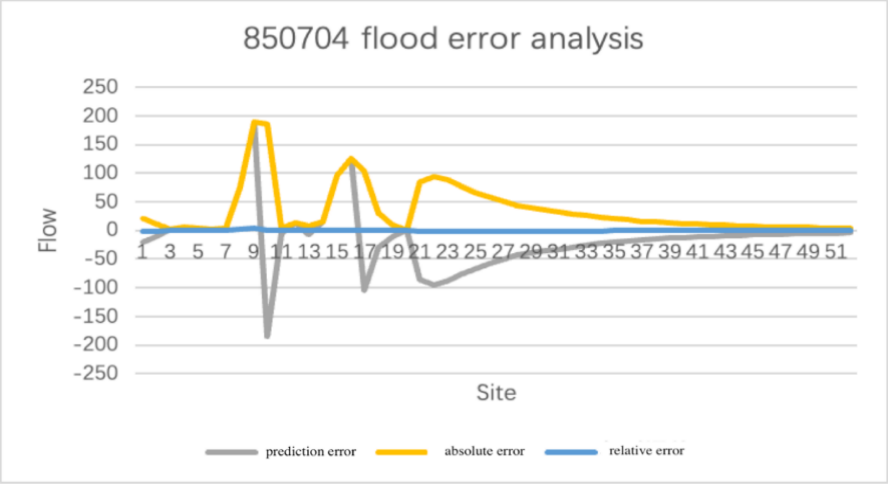


Figure 4. Flood 850704 error analysis results

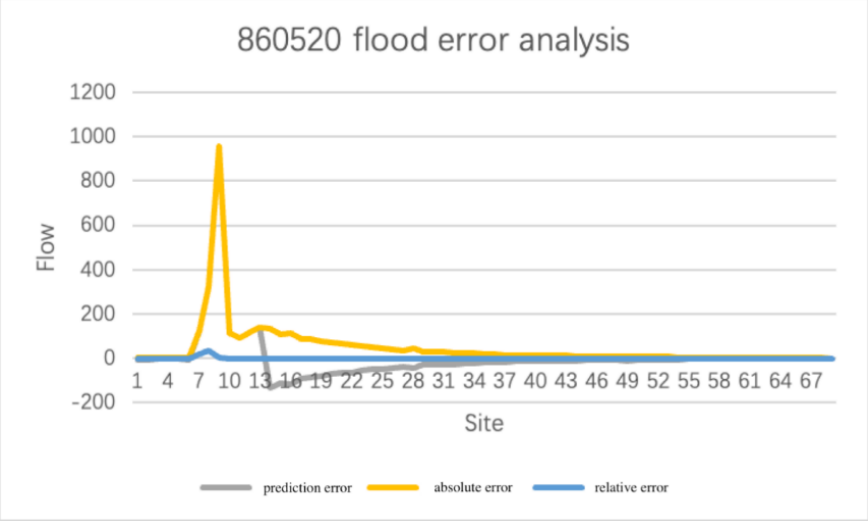


Figure 5. Flood 860520 error analysis results

The degree of agreement between the flood forecasting process and the measured process can be indicated by the coefficient of certainty, which is given in the following equation.

$$DC = 1 - \frac{\sum_{i=1}^{n}(y^{prediction} - y^{measure})^2}{\sum_{i=1}^{n}(y^{prediction} - y^{real\ uniform})^2} \quad (1)$$

According to the data, the coefficient of certainty of the flood 850704 forecast is DC=0.64, and the accuracy of this flood forecast can be classified as grade C from Table 4 of the accuracy level of forecast items;

According to the data, the coefficient of certainty of the flood 860520 forecast is DC=0.69. As shown in Table.4, the accuracy of this flood forecast can be classified as Grade C [10].

Table 4. Scale of Precision for Forecast Items

Accuracy Class	First	Second	Third
Certainty Coefficient	DC>0.90	0.90≥DC≥0.70	0.70≥DC≥0.50

4. Conclusion

In this study, the Xin'an River model was used to forecast the flood of PanShiTou Reservoir, and the applicability of the model in reservoir flood forecasting was verified by parameter rate setting and error analysis. Although the prediction accuracy of the two floods only reached grade C, this study provides a feasible method for reservoir flood prediction. The model parameters can be further optimized in the future to improve forecasting accuracy. Meanwhile, the Xin'an River model can also be applied to flood forecasting in other basins to provide a scientific basis for the safe operation of reservoirs. This study provides technical support for reservoir scheduling and management and serves as a reference for flood forecasting studies of other reservoirs.

References

[1] Situ Z, Wang Q, Teng S, et al. Improving urban flood prediction using LSTM-DeepLabv3+ and Bayesian optimization with spatiotemporal feature fusion [J]. Journal of Hydrology, 2024, 630.

[2] Dandan S, Weimin B, Peng N. A robust real-time flood forecasting method based on error estimation for reservoirs [J]. AQUA — Water Infrastructure, Ecosystems and Society, 2022, 71 (4).

[3] Wang Y, Zhong A P, Zhu F, et al. A modified Xin'anjiang model and its application for considering the regulatory and storage effects of small-scale water storage structures [J]. Journal of Hydrology, 2024, 630.

[4] Tun T Z, Minjiao L. Influence of Data Length on the Determination of Data Adjustment Parameters in Conceptual Hydrological Modeling: A Case Study Using the Xinanjiang Model [J]. Water, 2022, 14 (19).

[5] Shuaihong Z, Zhijia L, Cheng Y, et al. A New Runoff Routing Scheme for Xin'anjiang Model and Its Routing Parameters Estimation Based on Geographical Information [J]. Water, 2020, 12 (12).

[6] Pidal M I, Martín H A J, Alonso-Muñoyerro M J, et al. Real-Time Data and Flood Forecasting in Tagus Basin. A Case Study: Rosarito and El Burguillo Reservoirs from 8th to 12th March, 2018 [J]. Water, 2020, 12 (4).

[7] Chenkai C, Jianqun W, Zhijia L, et al. A New Hybrid Framework for Error Correction and Uncertainty Analysis of Precipitation Forecasts with Combined Postprocessors [J]. Water, 2022, 14 (19).

[8] Hortal P A A, Zawadzki I, Yau K M. A Heuristic Approach for Precipitation Data Assimilation. Effect of forecast errors and assimilation of NCEP Stage IV precipitation analyses A Heuristic Approach for Precipitation Data Assimilation. Effect of forecast errors and assimilation of NCEP Stage IV precipitation analyses [J]. Monthly Weather Review, 2020, 148 (4).

[9] Ali F, Achraf H, Guillaume F, et al. A novel statistical model for flood prediction in the Eel River watershed, New Brunswick, Canada [J]. Water Science, 2023, 37 (1).

[10] Yizhi W, Jia L, Chuanzhe L, et al. A data-driven approach for flood prediction using grid-based meteorological data [J]. Hydrological Processes, 2023, 37 (3).