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Application of Hydrological Model to Simulate Rainfall-Runoff into An Khe Reservoir in the Ba River Basin, Vietnam

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Abstract: The BR (Ba River) basin is one of 9 main river basins in Vietnam. In the past 20 years, natural hazards such as flood and inundation have been complex and increased dramatically in both frequency and intensity in the BR basin. Recently, there have been approximately 198 large and small operating reservoirs which lead to increase natural hazards in the river basin. An Khe reservoir, one of big reservoirs in the upstream of the Ba river, impacts significantly on flooding in the downstream. This paper uses hydrological model to simulate the flows as a basic for the safety operation of An Khe reservoir in order to prevent the downstream floods. The results indicate the Nash-Sutcliffe coefficient higher than 0.8 is stable and reliable parameter.

Key words: Ba river basin, flood, An Khe reservoir, hydrographic model, rainfall-runoff.

1. Introduction

1.1 Natural Condition of the Ba River Basin

The BR (Ba River) basin belongs to the administrative boundaries of 20 districts and one city of the three provinces in Central Highlands including Kon Tum, Gia Lai, Daklak and the Southern Central coastal province of Phu Yen.

The BR basin is mostly L-shaped with narrow upstream and downstream and middle river basin in an average of 48.6 km wide and the widest of 85 km. BR flows into the sea in three main directions: (1) Northwest-Southeast direction is from Ngoc Ro mountain peak of about 1,549 m high of Truong Son range to An Khe; (2) North-South direction is from An Khe to Hinh river and (3) West-East direction is from Hinh river into the East Sea at Tuy Hoa city.

The BR basin has an area of 14,140 km^2, the river length is approximately 388 km and the river density is about 0.22 km/km^2. The river basin expands less than others.

The river has many tributaries including more than 50 tributaries with the length of over 20 km and 19 tributaries with a basin area of over 100 km^2. There are three main tributaries: Ayun, Krông Hnang and Hinh river.

The Ayun river, is the largest tributary of the Ba river, originates from the Cong Lak mountain peak with a height of 1,720 m in the North-South direction and then turns to the Northeastern direction to the confluence with the BR at Cheo Reo. The main river length is 291.8 km and the basin area is 2,874 km^2.

Krông Hnang river, is the second largest tributary of the Ba river, originates from the Chu Tun Mountain peak with the height of 1,215 m in Northeast-Southwest direction and then flows in the North-South direction and moves to the arc-shaped in the opposite direction to the confluence with the BR at the boundaries of Gia Lai and Phu Yen provinces. The

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length of Krông Hnang river is 130 km and the basin area is 1,761 km^2.

The Hinh river, is the third largest tributary of the BR, originates from Chu Hreu Mountain peak with the height of 2,051 m in Southwest-Northeast direction and then flows in many directions, finally followed by South West-North East to the confluence with BR at Son Hoa. The Hinh river has a basin area of 1,040 km^2 and a length of about 59 km (Fig. 1) [1, 2].

1.2 Characteristics of An Khe Flows

In the BR basin, the fluctuations of seasonal flow are quite complex. Floods in this river happen two to three months sooner or later than that in other rivers. The length of annual flood season varies in years: 2 to 3 months or 5 to 6 months. Because the Southwest monsoon comes strongly from the beginning of rainy seasons (May), flood seasons in the basin start early. In the case that typhoons and tropical depressions from the East Sea appear at the end of rainy season, the flood season will last, even to next January. Particularly, the Hinh river and other small streams in the downstream are impacted solely by the climate of the East Truong Son, so the seasonal flow is more stable.

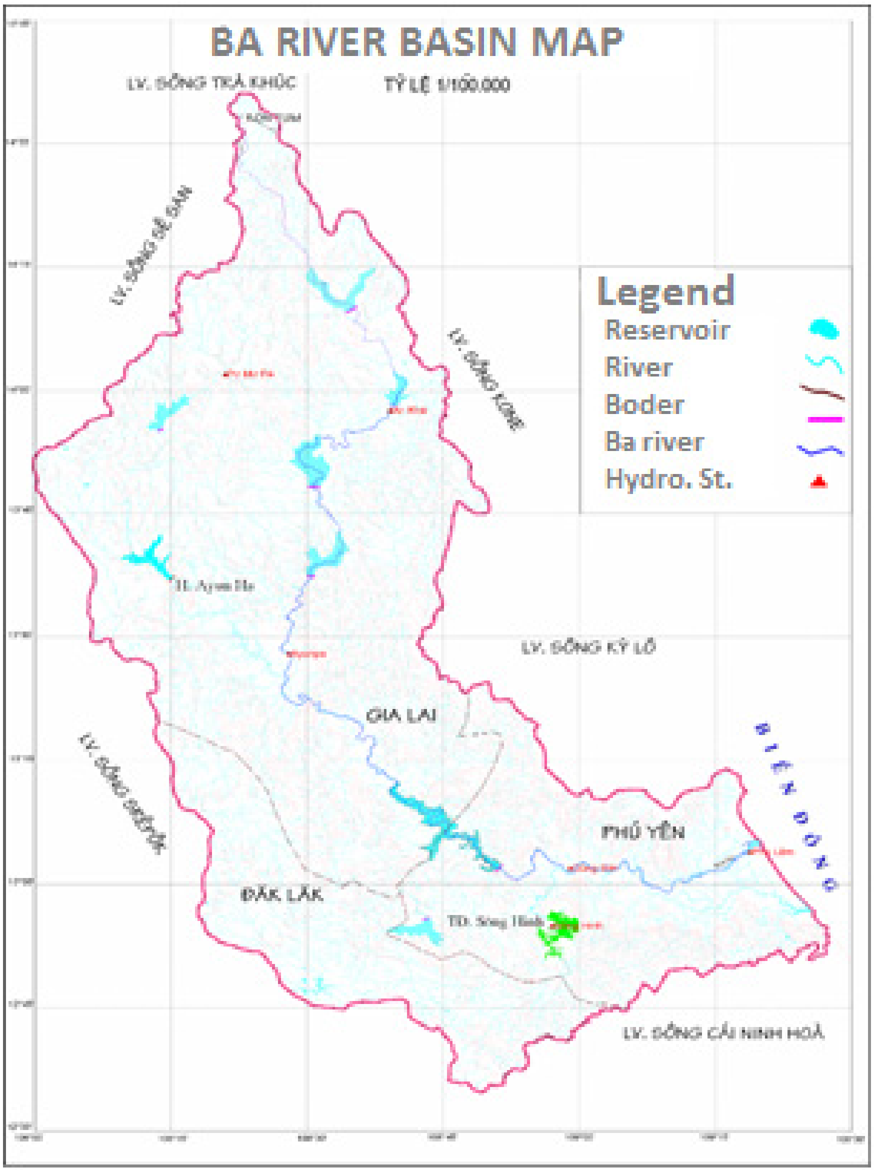

Fig. 1 Ba river system map.

In the upstream of the BR: Flood season lasts 3 to 4 months from September to December. The annual flood flow rate was high (the highest was up to 90% in 1983 and 1998, the lowest was 30% in 1982). The highest flow was in October, occupying average 46% of flood season flow [1].

In the An Khe tributary, flood water level was higher than WWL (Water Warning Level) II in 21 years, which appeared 2 times in 2 months of 7 years and higher than WWL III in 15 years, which appeared 2 times in 2 months of 4 years. The typical floods were in years: about 1.05 m higher than WWL III in 1980; around 1.98 m higher than WWL III in 1981 and approximately 1.65 m higher than WWL III in 2007. These years including 1978, 1979, 1982, 1989, 2006 and 2012 have small floods [1, 3].

The An Khe-Ka Nak reservoirs located in the upstream of the BR were built together to improve the efficiency of electricity generation. Ka Nak reservoir regulates about 285.5 million m^3/yr and provides a water level of 357 m for electricity generation at An Khe hydropower plant.

According to design for flow rate from Ka Nak reservoir to hydropower plant, the average flow rate is 11 m^3/s, the largest flow is 42 m^3/s. With An Khe reservoir, the average and highest flows rate are 9.6 m^3/s, and 50 m^3/s respectively [1, 4].

According to reservoir operation data in 2 years 2011 and 2012, in the dry season, the flow rate of Ka Nak reservoir was the highest of about 30 m^3/s, average of 15 m^3/s and the smallest of about 13.1 m^3/s. Meanwhile, An Khe reservoir had the highest flow rate of about 48-50 m^3/s and average 24 m^3/s. By the end of the dry season in 2012, the water level of Ka Nak reservoir was quite high to supply a large amount of water for the operation of An Khe factory. In the flood season year 2012, the flow of An Khe reservoir was very small without floods while Ka Nak reservoir decreased electricity generation to accumulate water, but still 7.0 m lower than that in statistics (Fig. 2) [1].

The inundation region in downstream of the An Khe reservoir: An Khe town, located on the National Road 19 from Binh Dinh town (An Nhon) to Pleiku, is between An Khe Pass (border Tay Son district, Binh Dinh province) and Mang Yang Pass (border Mang Yang district, Gia Lai province). According to An Khe Hydrological Station data, many areas become inundated due to the increase in flood water level, including the downstream areas which are about 8.5 km far from An Khe reservoir and approximately 33 km far from Kanak reservoir. Therefore, flood prevention depends on the operation of these reservoirs. The relationship between total utilizable storage capacity of An Khe and Ka Nak reservoirs and the highest total flow volume in 10 days within the period of 32 years revealed that the total flood volume was higher than utilizable storage capacity in 12 years, in which, the total flood volume is 0.6 times higher than utilizable storage capacity in 11 years. Therefore, in devastating flood years, both two lakes discharge to death water level to control floods but it is not able to control floods thoroughly. As a result, reservoirs will only be able to support flood reductions for downstream area when they were assigned additional missions [1, 5].

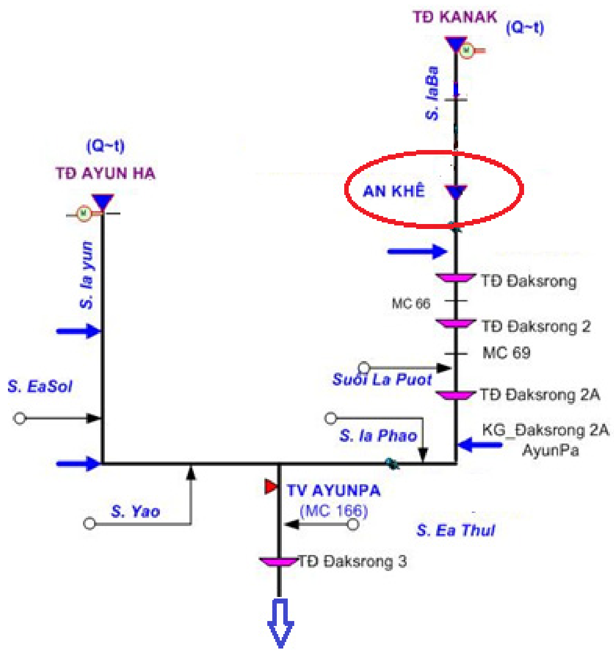

Fig. 2 An Khe reservoir location diagram.

2. Methodology

2.1 Hydrological Models

Hydrological models can be used to determine the boundary condition for hydraulic models. In hydrology, there are many functions of water concentration and there are many methods to build it. The isochronous flow method is based on the variability of flow rate to determine the area of isochronous flow and the concentration curve of water. The unit flow line method was first proposed by Sherman, and was developed and completed by many authors. The Kalinin-Miliukov concentration curve and the Nash unit hydrograph are shown as the adjustment in the rivers or in the river basins equivalent to the adjustment of a linear reservoir system.

Based on this assumption, although the step and specific solution of methods are different, but both of them lead to the concentration curve of water having a similar form as the Gamma function. Some of the synthetic unit flowlines such as Snyder, SCS and Clark... were developed to calculate for the river basins without data of flow measurement [6-8].

2.2 Structures of NAM Model (Rainfall-Runoff Model)

The NAM model stands the acronym in Danish “Nedbør Affstrømnings Model”, meaning rainfall-runoff model. NAM is a deterministic, conceptual and lumped hydrological model, was built in 1982 at the Faculty of Hydrology, DHI (Danish Hydraulic Institute), University of Technology Denmark. The NAM model is based on the principle of five storages: snow storage; surface storage; lower zone storage; upper groundwater storage and underground water storage.

The basic inputs for the NAM model include: model parameters, initial conditions, meteorological data, flow data for model calibration and verification [2, 6, 9].

The NAM model is based on the structures and physical equations which are used together with the semi-experience formula. This is a lumped model which treats a whole catchment as a single unit. As a consequence, basin characteristics are represented as average values for the hydrologic processes over the catchment as a whole.

The model structure is shown in Fig. 3. The NAM model simulates the rainfall-runoff process by continuously calculating the amount of water in storages that are related to each other, which depicts the physical composition of the different basins. These storages include surface storage, lower zone storage and underground storage. Furthermore, the NAM model allows the processing of human intervention in the hydrological cycle, such as irrigation and groundwater extraction [9, 10].

Based on meteorological data, the NAM model generates flow as well as information about soil layers in the hydrological cycle, such as the temporal variability of evapotranspiration, soil moisture, intake of underground water, underground water level, etc..

The conceptual flow of the basin is divided into surface flow, sub-surface flow and underground flow.

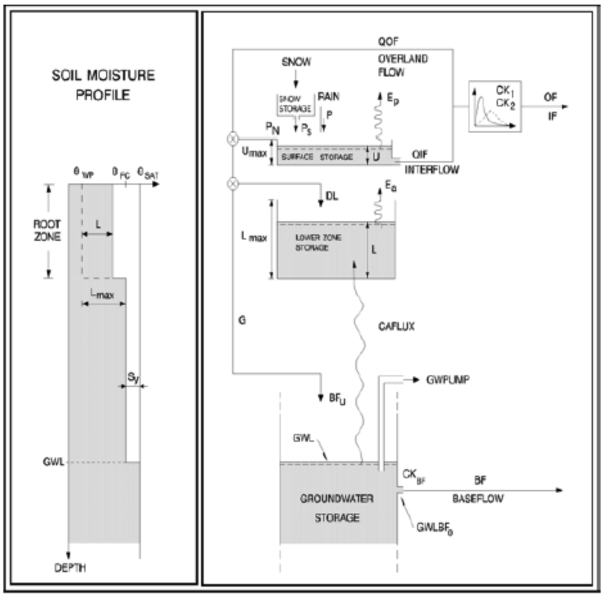

Fig. 3 Structure of NAM model for rainfall-runoff simulation.

2.3 Composition of Rainfall-Runoff Model (NAM)

Maximum water content in surface storage (U_{max}): represents the cumulative total water content of interception storage and storage in the upper layers of soil.

Maximum water content in root zone storage (L*max*): represents the maximum moisture content in soil in the root zone.

Snow storage: rainfall will be held in the snow storage when temperature is below 0 °C, if temperature is higher than 0 °C, it will move to the surface storage:

$$Q_{melt} = \begin{cases} CSNOW\ TEMP & khi\ TEMP > 0 \\ 0 & khi\ TEMP \leq 0 \end{cases}$$

CSNOW = 2 mm/day/K—snowmelt coefficient during the day.

Evaporation: If the amount of moisture U in the surface storage is less than this demand, it will get moisture from the root layer followed by the rate E_a. E_a is proportional to potential evapotranspiration E_p:

$$E_a = E_p\ L/L_{max}$$

Surface runoff: When the surface storage overflows, $U \geq U_{max}$, the amount of water that exceeds the P_N will form the surface runoff and infiltrate. QOF is part of P_N, participates in surface runoff formation, it is proportional to P_N and changes linearly with relative humidity, L/L_{max}, of root layer:

$$QOF = \begin{cases} CQOF \dfrac{L/L_{max} - TOF}{1 - TOF} P_N & khi\ L/L_{max} > TOF \\ 0 & khi\ L/L_{max} \leq TOF \end{cases}$$

CQOF is coefficient of overland flow (0 ≤ CQOF ≤ 1).

TOF is threshold value of overland flow (0 ≤ TOF ≤ 1).

Interflow: Interflow QIF, is assumed to be proportional to U and linearly transformed with the relative humidity of the root tank:

$$QIF = \begin{cases} (CKIF)^{-1} \dfrac{L/L_{max} - TIF}{1 - TIF} U & khi\ L/L_{max} > TIF \\ 0 & khi\ L/L_{max} \leq TIF \end{cases}$$

CKIF is time constant for routing interflow; TIF is root zone threshold value for interflow (0 ≤ TIF ≤ 1) [9].

3. Results

Simulation result from 1st January 1986 to 31st December 1986 is shown as Fig. 4.

Simulation result from 1st January 1988 to 31st December 1988 is shown as Fig. 5.

Simulation result from 1st January 2003 to 31st December 2003 is shown as Fig. 6.

Results of error evaluation are in Table 1.

Hydrograph error:

$$NASH(EI) = 1 - \frac{\sum (Qcal - Qobs)^2}{\sum (Qobs - Qobsaver)^2}$$

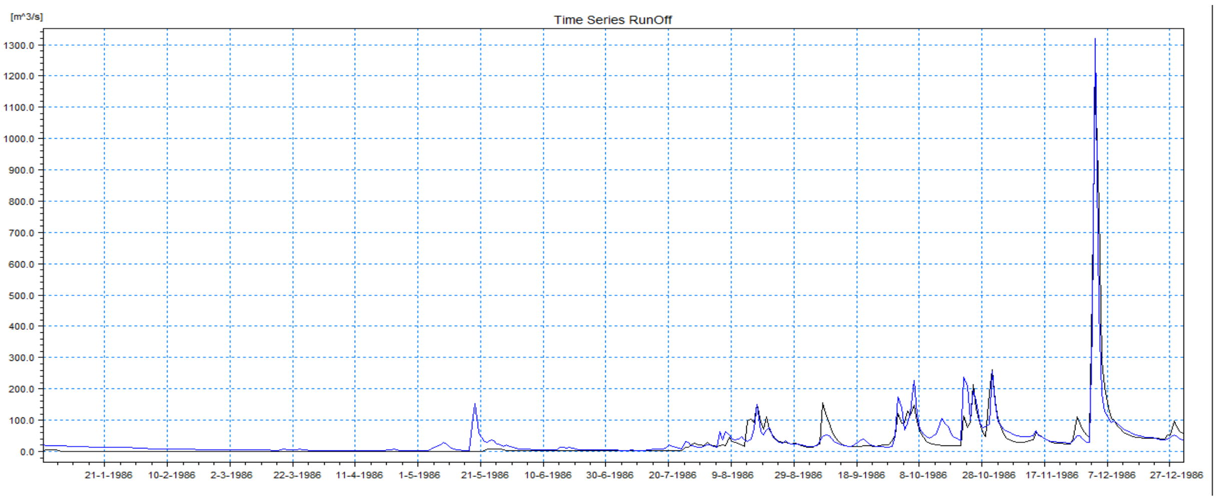

Fig. 4 Comparing observed and simulated flow rate to the An Khe reservoir in 1986.

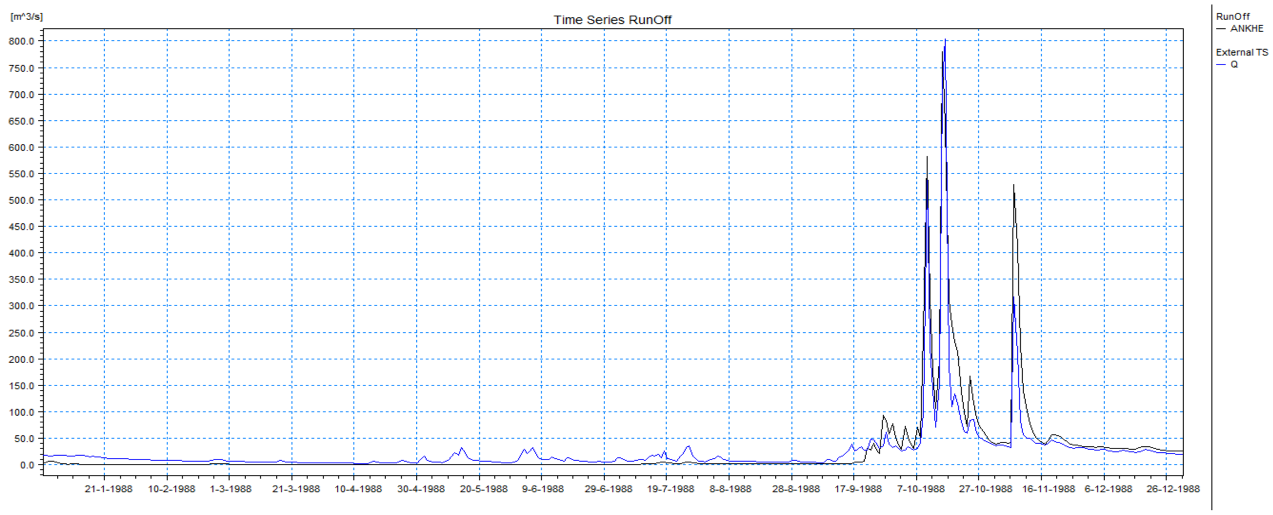

Fig. 5 Comparing observed and simulated flow rate to the An Khe reservoir in 1988.

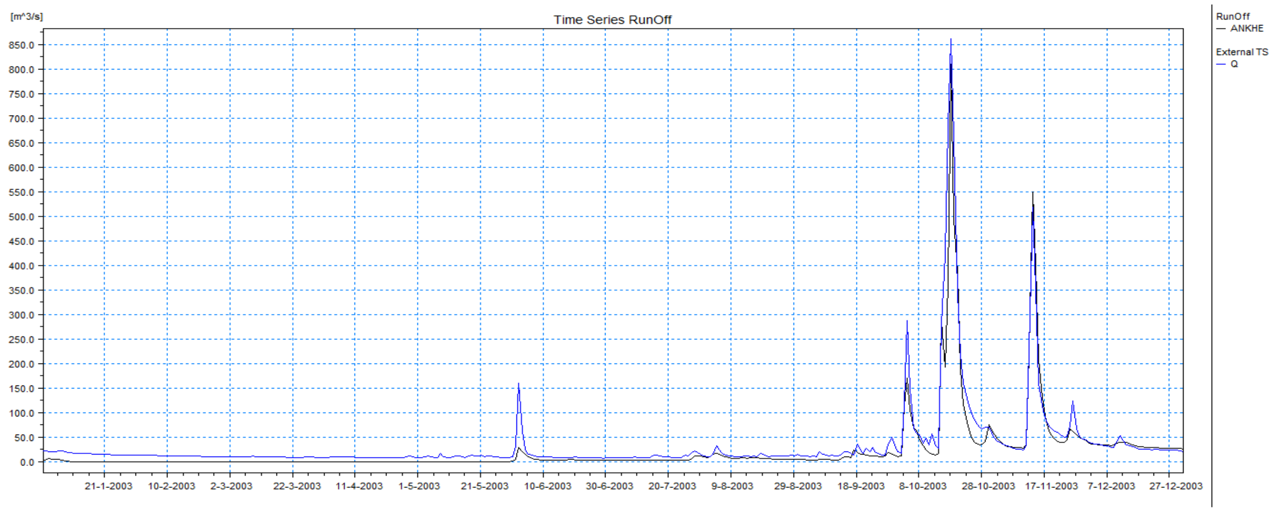

Fig. 6 Comparing observed and simulated flow rate to the An Khe reservoir in 2003.

Table 1 Results of error evaluation.

Indicators	1986	1988	2003
Nash	0.86	0.82	0.89
ΔQmax (%)	9.8	2.9	6.1

Table 2 Results of NAM model parameters.

No.	Parameters	Value
1	Umax	15.3
2	Lmax	120
3	CQOF	0.61
4	CKIF	304.2
5	CK12	21.5
6	TOF	0.507
7	TIF	0.328
8	TG	0.134
9	CKBF	2507

in which, Qcal—calculated flood flow rate (m^3/s);

Qobs—observed flood flow rate (m^3/s);

Qobsaver—average observed flood flow rate (m^3/s).

Flood peak error ($\Delta Qmax$):

$$\Delta Qmax = \left| \frac{Q_{max}^{tt} - Q_{max}^{td}}{Q_{max}^{td}} \right|$$

in which: Q_{max}^{tt}—simulated flood peak;

Q_{max}^{td}—observed flood peak.

Model parameters: results of NAM model parameters are in Table 2.

4. Conclusions

Based on three flood events in the past with different characteristics, the study chose 3 years having typical floods which included:

The flood in 1986: flood peak is about 1,320 (m^3/s);

The flood in 1988: flood peak is about 804 (m^3/s);

The flood in 2003: flood peak is about 862 (m^3/s).

With different flood levels, the model parameters still give results quite good: the Nash-Sutcliffe coefficient is higher than 0.8 as good simulation level and flood peak errors are always smaller than 10% as acceptable error level. Therefore, NAM model could be used to simulate rainfall-runoff into An Khe reservoir for flood prevention and control in the downstream of the Ba river.

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