Calibration of semi-distributed hydrological model based on Dapoling-Wangjiaba catchment

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Abstract: Global warming has an increasing influence on human and environment, especially on hydrology and the water at the global scale. The hydrological model can simulate the hydrological processes more accurately nowadays. It is a common practice to use semi-distributed hydrological models in operational forecasting for a catchment. There is one case study that Dapoling-Wangjiaba catchment of Huai River in China for this research. One rainfall-runoff conceptual model (semi-distributed model) is used to simulate the discharge. Since the version of HBV model used differs from the previous researches and the semi-distributed model was built in the study, the model had to be calibrated. [1][2][3]

1. Description of the catchment

1.1 Watershed Overview
Huai River, is one of the important rivers in China, which is located in the eastern part of China (30°55’N–30°55’N, 111°55’E–121°25’E) with a length of 1100 km and a draining area of 174000 km². Huai River is situated between the Yangtze and Yellow rivers in Eastern China (Figure 1). Huai River is a significant natural climatic demarcation between southern and northern China. Along the Qinling Mountains-Huai River line, the temperature in January is higher than 0 and the annual precipitation is more than 800mm in southern China, but the climatic situation is opposite in northern China. There is a very complex atmospheric system and the precipitation is uneven in Huai River Basin, so it is very vulnerable to floods which occur about every five years. Therefore, this study of flood hazard change is very important. [1]

![Figure 1 Location of Huai River(Xu, 2014)](image)

1.2 Data Availability
There is 10 years (from 2001 January 1st to 2010 December 31st, 4 months missing) daily precipitation
data from 20 rain gauges was provided in the previous research. In this study, the Huai river commission provided more data. For discharge data, there is daily flow data of 6 stations during these 10 years (2001-2010), daily temperature data in Zhu Madian (from 2001 to 2007), Xin Yang (from 2001 to 2007) and Xi Xian (from 2001 to 2005).

The sub-catchments division is shown in the Figure 2. And the outlets of the sub-catchments are Da Poling, Ban Tai, Chang Taiguan, Xi Xian, Huai Bin and Wangjiaba, where the daily flow data have already been collected. The precipitations and temperature of each sub-catchment are calculated by using Thiessen polygon method. Then use the Hargreaves method to calculate the daily potential evapotranspiration.

1.3 HBV Model
The HBV model is a rainfall-runoff conceptual model, which was developed by the Swedish Meteorological and Hydrological Institute (Bergström 1976) and then improved by Lindström et al. (1997). It uses the input data of rainfall, temperature, and potential evaporation, to simulate the outlet runoff of a catchment. The observed discharge allows for model calibration, yielding the basis for the parameter identification.

1.3.1 Model Structure
HBV simulates the different processes of the water cycle. The structure of the HBV model is shown in Figure 3.

In this study, the HBV-96 lumped model implementation by Juan Chacon in Python, which has four main routines of HBV model we used: precipitation routine, snow routine, soil routine and a response routine. The inputs of the model are daily precipitation P, daily temperature T, and daily potential evapotranspiration PET. Total catchment area and the fraction of the catchment with forest cover are
used as variables. The model calculates all fluxes and storage terms in unit [mm] with a daily time step. Model output is a time series of simulated discharge $Q_{sim}$. The following model structure descriptions are based on the explanation in Python code by Juan Chacon.

The first routine module is precipitation routine. If the temperature is lower than the lower threshold level, all precipitation is seen as snowfall.

$$ rainfall = 0, snowfall = prec \times sfcf $$

At the same time, the precipitation is considered as rainfall when the temperature is above the upper-temperature threshold.

$$ snowfall = 0, rainfall = prec \times rfcf $$

In case that the temperature is between the lower threshold and upper-temperature threshold, there is a linear mixture of rainfall and snowfall.

$$ rainfall = \left(\frac{temp - ltt}{utt - ltt}\right) \times prec \times rfcf $$
$$ snowfall = \left(1 - \left(\frac{temp - ltt}{utt - ltt}\right)\right) \times prec \times sfcf $$

Where prec is precipitation, temp is measured temperature, sfcf is snowfall corrector factor, rfcf is rainfall corrector factor, ltt is lower temperature threshold and utt is upper temperature threshold.

The snow pack consists of two states: Water Content (wc) and Snow Pack (sp). The water content states correspond to the liquid part of the water in the snow and the snow pack states correspond to the solid part. If the temperature is higher than the melting point, the snow pack will melt and the solid snow will become liquid. In the opposite case, the liquid part of the snow will refreeze, and turn into solid. The water that cannot be stored by the solid part of the snow pack will drain into the soil as part of infiltration.

$$ snowmelt = cf_{max} \times (t - ttm) $$

Where ttm is the threshold temperature, t is the temperature and cfmax is day degree factor.

$$ refreezingmeltwater = cfr \times cf_{max} \times (t - tt) $$

Where cfr presents the refreezing factor.

Soil routine model checks for the amount of water that can infiltrate the soil, which is from the liquid precipitation and the snow pack melting. Some water will be retained as soil moisture, while others will become runoff, and will be routed to the upper zone tank. [2]

At first, comparison of temperature is made. If the temperature is below the threshold, melting is happening, otherwise, refreezing. If the water content in the snow pack is bigger than water holding capacity, excess infiltrates the soil.

The actual evapotranspiration $ea$ from the soil moisture storage is calculated from the potential evapotranspiration $ep$ using the following formula:

$$ if \ sm < fc \times lp, ea = ep \times \left(\frac{sm}{fc \times lp}\right) $$
$$ if \ sm < fc \times lp, ea = ep \times \left(\frac{sm}{fc \times lp}\right) $$

Where lp is the soil wilting point. The response module transfers the current values of upper and lower zone into the discharge. This routine also controls the recharge of the lower zone tank. Excess water or recharge $r$ goes to the upper reservoir, and the outflow is calculated as follows:

$$ q_o = k \times uz^{(1+alfa)} $$

Where $k$ presents the upper zone response coefficient, $uz$ is the storage in the upper reservoir, and alfa is response box parameter. There is also a capillary flux $cf$ from the upper reservoir to the soil moisture zone, which is calculated by the following formula:

$$ cf = tfac \times c\_flux \times \left(\frac{fc - sm}{fc}\right) $$

Where $c\_flux$ is the capillary flux in the root zone. The outflow of the lower reservoir can be gotten by
the following formula:

\[ q_1 = k_1 \times l_z \]

Where \( k_1 \) presents the lower zone response coefficient, and \( l_z \) is the new value of direct runoff into upper zone. The runoff \( q \) is computed as follows:

\[ q = \text{area} \times \left( \frac{(q_0 + q_1)}{3.6 \times t_{fac}} \right) \]

Where the area is the catchment area and \( t_{fac} \) is a time factor.

The routing function implements the transfer function using a triangular function defined by parameter maxbas. It consists of four main modules with 18 parameters in this model. (Table 1)

| parameters | description                                      | unit   |
|------------|--------------------------------------------------|--------|
| lt         | Lower temperature threshold                      | °C     |
| ut         | Upper-temperature threshold                      | °C     |
| ttm        | The temperature threshold for Melting            | °C     |
| cfmax      | Day-degree factor                                | -      |
| fc         | Filed capacity                                    | mm     |
| ccorr      | Evapotranspiration corrector factor              | -      |
| etf        | Total potential evapotranspiration               | mm     |
| lp         | soil moisture value where soil moisture reaches maximum potential | -      |
| k upper zone | Upper zone response coefficient | 1/d     |
| k1 lower zone | Lower zone response coefficient | 1/d     |
| alpha      | upper zone runoff coefficient                    | 1/d    |
| beta       | Shape coefficient for effective precipitation separation | -    |
| cwh        | Capacity for water holding in the snow pack      | -      |
| cfr        | Refreezing factor                                | -      |
| c_flux     | Capillary flux in the root zone                  | mm/d   |
| perc       | Percolation(Maximum flux from Upper to Lower zone) | mm/d   |
| rfcf       | Rainfall corrector factor                        | -      |
| sfcf       | Snowfall corrector factor                        | -      |
| Maxbas     | Flow routing coefficient                         | d      |

1.3.2 Semi-distributed Model

The semi-distributed model used is half distributed concept model for sub-basin dividing based on DEM. Through dividing sub-basin or different parts of the area, it shows that the differences of the underlying surface and rainfall space distribution. (Zhou et al. 2017)

These parameters correspond to a lumped model, which treats the complete basin as homogeneous. (Khakbaz et al. 2012) In this study, a semi-distributed model has been built, which attempt to calculate flow contributions from sub-catchments that are seen as homogeneous themselves. The lumped model and semi-distributed are different, which not only because their sophistication, but also the purposes they can to be used. The lumped model usually used as flowing purpose

- Control and infill the missing data;
- Expansion the historic flow records;
- Generate of synthetic data runs for civil engineering design work and other applications;
- Water resources assessment;
- Water resources management including real-time forecasting.

However, in this study, we should explore the climate change and forecast the future of spatial scenarios. The lumped model is not enough, and the semi-distributed model will offer the better potential.
2. HBV Model Calibration

The HBV model is a rainfall-runoff conceptual model, which was developed by the Swedish Meteorological and Hydrological Institute (Bergström 1976) and then improved by Lindström, Johansson et al. (1997). It uses the input data of rainfall, temperature and potential evaporation, to simulate the outlet runoff of a catchment. The observed discharge allows for model calibration, yielding the basis for the parameter identification.

The model parameters cannot be measured and have to be determined by the model calibration. Calibration is a process in which parameters adjustments are made in order to simulate as closely as possible to the hydrological behavior of the catchment. The model is calibrated by trial-and-error. The optimization algorithm used in this study is ALHSO (Augmented Lagrangian Harmony Search Optimizer).

The model performance measure used in this study is NSE (Nush-Sutcliffe Efficiency), which is calculated as follows:

\[
E = 1 - \frac{\sum_{t=1}^{T} (Q_{\text{sim}}^t - Q_0^t)^2}{\sum_{t=1}^{T} (Q_0^t - \bar{Q}_0)^2}
\]

In this equation, Qsim is simulated discharge, and Qo is the mean of observed discharges. Q_0^t is observed discharge at time t.

Nash–Sutcliffe efficiency is intended to range from −∞ to one. An efficiency of 1 (E=1) corresponds to a perfect match of simulated discharge to the observed data. An efficiency of 0 (E=0) indicates that the model predictions are as accurate as the mean of the observed data, whereas an efficiency less than zero (E < 0) occurs when the observed mean is a better predictor than the model or, in other words, when the residual variance (described by the numerator in the equation above), is larger than the data variance (described by the denominator). The closer the model efficiency is to 1, the more accurate the model is.

For lumped model, use the observed discharge in the outlet of whole Dapoling-Wangjiaba catchment (Wangjiaba station) to compare with the simulated discharge to calibrate. [2][3][4][5][6]

For semi-distributed model, the sub-catchments are calibrated using flow at the outlet of the sub-catchment, one by one from the upstream to the downstream sub-catchments. When calibrating the sub-catchment, the simulated discharge of sub-catchment is divided into two parts: discharge simulated by lumped model and discharge from upstream using a triangular function, which is shown as follow:

![Figure 4](image.png)

3. Result Analysis

3.1 Sub-catchment Model Calibration

3.1.1 Da Poling
Da Poling sub-catchment is located at the upstream of the Dapoling-Wangjiaba catchment, which is about 1733.496 km². The parameters of the HBV model and their ranges for this sub-catchment are shown in the following Table 2. The parameters and method to calibrate the upstream sub-catchments have no difference with the whole sub-catchment.

| Parameters | lower boundary | upper boundary | calibrated value |
|------------|----------------|----------------|------------------|
| ltt        | -2.500         | 0.500          | -1.162           |
| utt        | 0.001          | 3.000          | 2.552            |
| ttm        | 0.000          | 2.000          | 0.129            |
| cfmax      | 0.040          | 0.800          | 0.614            |
| fc         | 50.000         | 500.000        | 135.366          |
| ecorr      | 0.600          | 1.400          | 1.400            |
| etf        | 0.001          | 5.000          | 0.633            |
| lp         | 0.100          | 0.500          | 0.276            |
| k upper zone | 0.050        | 0.600          | 0.578            |
| kl lower zone | 0.000        | 0.140          | 0.125            |
| alpha      | 0.000          | 2.000          | 0.226            |
| beta       | 0.000          | 6.000          | 1.111            |
| cwh        | 0.001          | 0.100          | 0.058            |
| cfr        | 0.010          | 1.000          | 0.754            |
| c_flux     | 0.001          | 0.100          | 0.001            |
| perc mm/h  | 0.000          | 0.040          | 0.137            |
| rfcf       | 0.800          | 1.400          | 0.947            |
| sfcf       | 0.000          | 0.100          | 0.039            |
| Maxbas     | 1.000          | 6.000          | 2.425            |

The calibration period is also from 2001 January 1st to 2006 December 31st. The Nash-Sutcliffe efficiency of calibration dataset of Da Poling sub-catchment is 0.9095.

As the following Figure 5 indicates, there was higher peak flow in 2005 and many peak flows in 2003.
3.1.2 Ban Tai
Ban Tai sub-catchment is the other upstream sub-catchment, which located at the headstream of the tributary. The area of this sub-catchment is 9061.730 km². The following Table 3 indicates the parameters and boundaries for Ban Tai sub-catchment.

| Parameters | lower boundary | upper boundary | calibrated value |
|------------|----------------|----------------|------------------|
| ltt        | -2.500         | 0.500          | 0.481            |
| utt        | 0.001          | 3.000          | 1.437            |
| ttm        | 0.000          | 2.000          | 1.947            |
| cfmax      | 0.040          | 0.800          | 0.742            |
| fc         | 50.000         | 500.000        | 500.000          |
| ecorr      | 0.600          | 1.400          | 1.222            |
| etf        | 0.001          | 5.000          | 0.001            |
| lp         | 0.100          | 0.500          | 0.100            |
| k upper zone | 0.050        | 0.150          | 0.150            |
| k lower zone | 0.0001       | 0.120          | 0.120            |
| alpha      | 0.000          | 2.000          | 0.574            |
| beta       | 0.000          | 6.000          | 1.992            |
| cwh        | 0.001          | 0.100          | 0.050            |
| cfr        | 0.010          | 1.000          | 0.996            |
| c_flux     | 0.001          | 0.100          | 0.001            |
| perc mm/h  | 0.000          | 0.120          | 0.120            |
| rfcf       | 0.800          | 1.400          | 1.054            |
| sfcf       | 0.000          | 0.100          | 0.000            |
| Maxbas     | 1.000          | 6.000          | 5.140            |

The calibration period of Ban Tai catchment is from 2001 January 1st to 2006 December 31st and the Nash-Sutcliffe efficiency is 0.8252. As the Figure 9 shows, there were more and higher peak flows in 2003 and 2005, which means the flood risks were high this year. The value of the peak flows in other two years was normal and the peak flows only occurred in summer.
The validation period of the Ban Tai sub-catchment is from 2007 January 1st to 2010 December 31st and the Nash-Sutcliffe efficiency is 0.6222. It can be seen in the following Figure 11, more and higher peak flows occurred in and there was a very high flow in 2007.

3.1.3 Chang Taiguan
Chang Taiguan sub-catchment is located at the downstream of Da Poling sub-catchment, with 1290.2373 km² area.

There are the parameters ranges and value showed in the Table 4. Compared with the whole Dapoling-Wangjiaba catchment and two upstream sub-catchments, Chang Taiguan sub-catchment has addition parameter should be calibrated owning to the flow from the upstream Chang Taiguan, which is the maxbas.

| Parameters | lower boundary | upper boundary | calibrated value |
|------------|----------------|----------------|------------------|
| ltt        | -2.500         | 0.500          | 0.482            |
| utt        | 0.001          | 3.000          | 0.247            |
| ttm        | 0.000          | 2.000          | 1.986            |
| cfmax      | 0.040          | 0.800          | 0.750            |
| fc         | 50.000         | 500.000        | 499.956          |
| ecorr      | 0.600          | 1.400          | 0.831            |
| etf        | 0.001          | 4.000          | 0.449            |
| lp         | 0.100          | 1.000          | 0.100            |
The calibration results of Chang Taiguan sub-catchment is fine but not as good as other sub-catchments, which Nash-Sutcliffe efficiency is 0.3224. Besides the reason of area, it is also because the value of flow in this sub-catchment is very small and it goes up to peak value and down to low flow rapidly. For the weak performance of peak value and HBV model, the sharp changes cannot be simulated.

The Nash-Sutcliffe efficiency of validation result is 0.1613. As can be seen clearly from the Figure 15 there are not many high flows, which the normal discharge is low and jump to the peak value suddenly. It is confirmed that the Nash-Sutcliffe efficiency is lower than other sub-catchment results from the foible of the model.
3.1.4 Xi An
The water flows to Xi Xian sub-catchment is from Chang Taiguan sub-catchment. Xi Xian sub-catchment’s area is about 7193.5905 km². The Table 5 provides the parameters ranges and value, also includes maxbas to calculate the discharge from the outlet of the upstream Chang Taiguan sub-catchment.

Table 5 Parameters and their ranges for Xi Xian sub-catchment

| Parameters          | lower boundary | upper boundary | calibrated value |
|---------------------|----------------|----------------|------------------|
| ltt                 | -2.500         | 0.500          | 0.499            |
| utt                 | 0.001          | 3.000          | 1.131            |
| ttm                 | 0.000          | 2.000          | 0.001            |
| cfmax               | 0.040          | 0.800          | 0.791            |
| fc                  | 50.000         | 500.000        | 499.992          |
| ecorr               | 0.600          | 1.400          | 0.741            |
| etf                 | 0.001          | 4.000          | 1.447            |
| lp                  | 0.100          | 1.000          | 0.890            |
| k upper zone        | 0.050          | 0.280          | 0.280            |
| k1 lower zone       | 0.0001         | 0.150          | 0.066            |
| alpha               | 0.000          | 2.000          | 0.387            |
| beta                | 0.000          | 4.000          | 2.367            |
| cwh                 | 0.001          | 0.100          | 0.001            |
| cfr                 | 0.010          | 1.000          | 0.461            |
| c_flux              | 0.001          | 0.100          | 0.001            |
| perc mm/h           | 0.000          | 0.120          | 0.108            |
| rfcf                | 0.800          | 1.000          | 0.802            |
| sfcf                | 0.000          | 0.500          | 0.397            |
| Maxbas              | 1.000          | 1.100          | 1.049            |
| Maxbas (xixian from changtaiguan) | 1.100 | 6.000 | 2.825 |

The Nash-Sutcliffe efficiency of calibration results is 0.6154. It is been shown in the Figure 17 that the performance of the model is good and the model states also perform well without strange trends.

Figure 17 Simulated discharge of Xi Xian sub-catchment for the calibration dataset
Figure 18 Model states (above: soil moisture, below: lower zone and upper zone) of validation results
Validation result's Nash-Sutcliffe efficiency is 0.4153. As can be seen from the Figure 19, 2007 and 2008 have more and higher flows, which rise to peak value sharply.

Figure 19 Simulated discharge of Xi Xian sub-catchment for the validation dataset

Figure 20 Model states (above: soil moisture, below: lower zone and upper zone) of validation results

3.1.5 Huai Bin
The area of Huai Bin sub-catchment is around 5542.0313 km², which located at the downstream of Xi Xian sub-catchment. Therefore, there is a parameter maxbas to estimate the discharge from the outlet of the upstream Xi Xian sub-catchment need to calibrate.

| Parameters     | lower boundary | upper boundary | calibrated value |
|----------------|----------------|----------------|-----------------|
| ltt            | -2.500         | 0.500          | -2.476          |
| utt            | 0.001          | 3.000          | 0.004           |
| ttm            | 0.000          | 2.000          | 1.978           |
| cfmax          | 0.040          | 0.800          | 0.087           |
| fc             | 50.000         | 500.000        | 430.401         |
| ecorr          | 0.600          | 1.400          | 1.040           |
| etf            | 0.001          | 4.000          | 0.002           |
| lp             | 0.100          | 1.000          | 0.174           |
| k upper zone   | 0.050          | 0.300          | 0.279           |
| k1 lower zone  | 0.0001         | 0.150          | 0.109           |
| alpha          | 0.000          | 2.000          | 0.297           |
| beta           | 0.000          | 4.000          | 3.338           |
| cwh            | 0.001          | 0.100          | 0.099           |
| cfr            | 0.010          | 1.000          | 0.856           |
| c_flux         | 0.001          | 0.100          | 0.001           |
| perc mm/h      | 0.000          | 0.080          | 0.080           |
| rfcf           | 0.800          | 1.000          | 0.940           |
| sfcf           | 0.000          | 0.500          | 0.500           |
| Maxbas         | 1.000          | 6.000          | 3.699           |
Maxbas (huabin from xixian) | 1. 100 | 6. 000 | 3. 145

Calibration Nash-Sutcliffe efficiency is 0. 8205. The highest flow occurred in 2002, and 2003, 2004 and 2005 all have high flows. However, from the news, it can be known not all these years have flooded in the main river. It may be because only one sub-catchment only has parts of influence.

Validation Nash-Sutcliffe efficiency is 0. 5836. 2007 and 2008 had the more and higher flows during the calibration periods. The efficiency of validation is a little weak, which is because the influence of the upstream sub-catchment. Another reason is the rapidly changes of the discharge in these years.

3.1.6 Wang Jiaba
Wang Jiaba sub-catchment located at the downstream of whole Dapoing-Wangjiaba Catchment. The area of this sub-catchment is about 4427. 7790 km². The following Table 7 illustrates the boundaries and calibrated value of the normal 18 parameters and 2 maxbas from two upstream sub-catchments (Ban Tai and Huai Bin)

![Figure 21 Simulated discharge of Huai Bin sub-catchment for the calibration dataset](image1)

![Figure 22 Model states (above: soil moisture, below: lower zone and upper zone) of validation results](image2)

![Figure 23 Simulated discharge of Huai Bin sub-catchment for the validation dataset](image3)

![Figure 24 Model states (above: soil moisture, below: lower zone and upper zone) of validation results](image4)

| Parameters | lower boundary | upper boundary | calibrated value |
|------------|----------------|----------------|-----------------|
| ltt        | -2. 500        | 0. 500         | 0. 493          |
| utt        | 0. 001         | 3. 000         | 1. 698          |
| ttm        | 0. 000         | 2. 000         | 0. 000          |
| cfmax      | 0. 040         | 0. 800         | 0. 792          |
| fc         | 50. 000        | 500. 000       | 427. 761        |
| ecorr      | 0. 600         | 1. 400         | 1. 102          |
| etf        | 0. 001         | 4. 000         | 0. 074          |
The Nash-Sutcliffe efficiency of calibration results is 0.8613. The Figure 25 describes the simulated discharge of the sub-catchment. In addition, 2003 and 2005 have more and high flows, which is similar to the lumped model results.

![Figure 25 Simulated discharge of Wang Jiaba sub-catchment for the calibration dataset](image1)

![Figure 26 Model states (above: soil moisture, below: lower zone and upper zone) of validation results](image2)

The Nash-Sutcliffe efficiency of validation results is 0.7046. Wang Jiaba as the outlet of the whole Dapoling-Wangjiaba catchment, the discharge trend of this sub-catchment of validation results is also similar with the lumped model, which can be concluded the performances of the lumped model and semi-distributed model are both good.

### Table

| Parameter       | Calibration | Validation | Maxbas (Wangjiaba) | Maxbas (Wangjiaba from Huaihui) |
|-----------------|-------------|------------|--------------------|---------------------------------|
| lp              | 0.100       | 1.000      | 0.809              |                                 |
| k upper zone    | 0.050       | 0.180      | 0.069              |                                 |
| k lower zone    | 0.0001      | 0.120      | 0.120              |                                 |
| alpha           | 0.000       | 2.000      | 0.511              |                                 |
| beta            | 0.000       | 4.000      | 1.965              |                                 |
| cwh             | 0.001       | 0.100      | 0.009              |                                 |
| cfr             | 0.010       | 1.000      | 0.772              |                                 |
| e_flux          | 0.001       | 0.100      | 0.002              |                                 |
| perc mm/h       | 0.000       | 0.080      | 0.080              |                                 |
| rfcf            | 0.800       | 1.000      | 0.878              |                                 |
| scrf            | 0.000       | 1.400      | 0.411              |                                 |
| Maxbas          | 1.000       | 1.100      | 1.036              |                                 |
| Maxbas (Wangjiaba from Bantai) | 1.100 | 6.000 | 4.920 |
| Maxbas (Wangjiaba from Huaihui) | 1.000 | 6.000 | 1.424 |
4. Conclusion

A semi-distributed model was built and calibrated in this study. The simulation results in the future were analysed. The conclusions for validation drawn from the results are:

- In the Da Poling catchment, there was more flows in 2007, as seen in our model state, which was higher than the other three years.
- In Ban Tai catchment, there are more and higher peak flows occurred in and there was a very high flow in 2007.
- The calibration results of the Chang Taiguan small catchment are not as good as other catchment. The validation results show that there is not a lot of high flows, the normal discharge is very low, and suddenly jumps to the peak.
- In Xi An, from 2007 to 2008, flows is getting higher and higher, and its peak is rising sharply.
- In Huai Bin catchment, in 2007 and 2008, flows increased during certain periods. The efficiency of the validation is somewhat weak, one of which is due to the influence of the upstream sub-set catchment. Another reason is the rapid changes in emissions over the years.

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