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Calibration and verification of a hydrological model using event data

Nguyen Tien Giang*, Tran Anh Phuong

Hanoi University of Science, VNU, 334 Nguyen Trai, Hanoi, Vietnam

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Abstract. The topic of calibration and verification of rainfall-runoff model has been subject of many researches. However, most of the researches using the continuous data for this task, while in the conditions of Vietnam, it is difficult to collect the sub-day continuous data. This leads to the need for methods that can calibrate and verify the model parameters from the event data. This paper introduces such a method. Idea of the method is to combine the auto-calibration and trial-and-error methods. Auto-calibration is executed to locate the optima sets of parameters for individual storm event by using the shuffled complex evolution algorithm. Then, the trial-and-error method will attempt to find the most suitable parameters for all of the events in the ranges defined by the parameters in the auto-calibration step. The method was applied to calibrate and verify MIKE-NAM model parameters with the case study of Ben Hai river basin. Because the searching space of parameters is narrowed, it is much easier and quick to find the best overall parameters than the traditional trial-and-error method.

Keywords: Rainfall-runoff, event data, auto- calibration, trial-and-error, searching space.

1. Introduction

Rainfall-runoff models are particularly effective tools to predict the responses of a basin with a given amount of rainfall. They, therefore, can be used for many purposes like flood forecast, planning, design, operation and management of the water resources systems. However, before applying them for these purposes, the models need to be calibrated and verified to ensure that they are accurate and persistent.

The topic of parameter calibration and validation has been the subject of many discussions. However, no consensus methodology exists [1,2]. There has been much attention given to specify the procedure for parameter calibration and validation using the continuous simulation [3-7], while a very limited attention has been so far devoted to solve the same problem with interrupted (event) data. The common way is using the continuous simulation with the long time series data. Compared with the continuous long time series of data, calibration using the event data is more difficult. Because the storm events occurred at different years, the basin conditions change, leading to the change of model parameters which represent for the basin characteristics. In that sense, a set of model parameters, that is optimal for this storm event, may be not suitable to other events. Another difficult for

* Corresponding author. Tel.: 84-4-35576903.
E-mail: giangnt@vnu.edu.vn

calibration with the discontinuous data is that we have to determine the initial conditions (state variables at the beginning of each event) which do not need for continuous simulation. The same amount of rainfall can cause a large, medium or small flood depending partly on the basin' hydrological pre-condition.

In the conditions of Vietnam where so far the sub-day data in long period have not been always available, the continuous simulation is impossible especially in the steep, small basins with short time of concentration. This leads to the demand that we have to calibrate and validate the hydrological model using the individual storm events. The traditional calibration method with the event data is trial-and-error, i.e. people run model with various sets of parameters for all of the events to find the best set among them. The drawbacks of this method are that 1) it depends on the experience of the user; 2) it takes a long time to calibrate because the parameter space is too large. Therefore, in this paper, we introduce a procedure to quickly calibrate and verify parameters of the rainfall-runoff model, MIKE-NAM, using interrupted data collected from different storm events in different years. Our idea is to combine two methods au-calibration and trial-and-error. Auto-calibration is to locate the optima set of parameters for each of the event by shuffled complex evolution algorithm available in MIKE-NAM model. Trial-and-error then will find the best parameters for all events in the parameter space defined by the optima sets of parameters in the auto-calibration step. This combination makes the calibration quickly because we do not need to use trial-and-error to find the optima parameters in their large origin space but in a narrow space determined in the auto-calibration step. The case study to illustrate for the method is Gia Vong, a small river basin in Quang Tri province.

The paper is organized as the following. Section 2 continues with the detail procedure to calibrate and verify the model parameters. Case study with Gia Vong river basin to illustrate for our method is introduced in section 3. Section 4 will close our paper with some conclusions obtained from the research.

2. Methodology

Figure 2.1 below presents the general procedure for model calibration and verification. As can be seen, the procedure includes six steps in which the first five steps are the calibration and the final step is the verification.

Selection of the simulation model: In order to simulate the rainfall-runoff processes, there are enormous numbers of numerical models depending on the purposes and characteristics of the applied region. The MIKE-NAM model developed by DHI Water & Environment was selected for the study. Basically, the model was constructed based on the idea that uses four different and mutually interrelated storages to represent for different physical elements of the basin. These storages are: snow storage, surface storage, lower zone (root zone) storage and ground storage (refer to [8] for more details on the theory of this model). The model has been widely used in Viet Nam for its simplicity and suitability with the Vietnamese basins' characteristics.

Determine model parameters for calibration and verification: MIKE-NAM works with several parameters divided into four groups: Surface and root zone, Groundwater, Snow melt, Irrigation. Because there is no intensive irrigation during the raining season in Quang Tri, no irrigation parameters have been used in this study. Also the snow melt parameters have been excluded, because the temperature in this province is almost never below 5°C. Therefore, there are total 9 parameters (table 2.1) needed to calibrate and verify in this study.

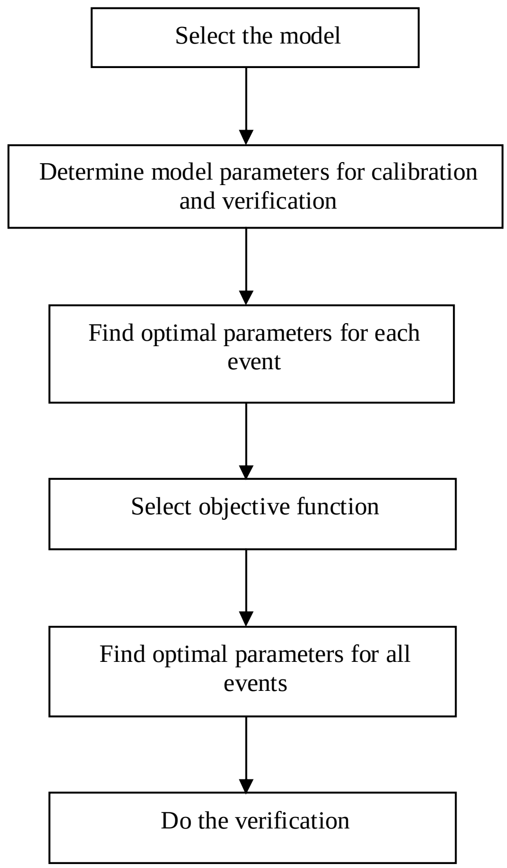


Figure 2.1. Procedure for parameter calibration and verification.

Shamsudin and Hashim [9] described the effects of these parameters on the total runoff volume and on the peak of the runoff. Their conclusions are shown in table 2.2.

Table 2.1. NAM parameter explanation and boundaries

NAM Parameter	NAM Parameter Description	Unit	Parameter boundaries
U_{max}	Maximum water content in surface storage	mm	10 – 20
L_{max}	Maximum water content in root zone storage	mm	50 – 300
CQOF	Overland flow runoff coefficient	-	0 – 1
CKIF	Time constant for routing interflow	hours	500 – 1000
$CK_{1,2}$	Time constant for routing overland flow	hours	3 – 48
TOF	Root zone threshold value for overland flow	-	0 – 0.7
TIF	Root zone threshold value for interflow	-	0 – 1
TG	Root zone threshold value for groundwater recharge	-	0 – 0.7
CKBF	Time constant for routing base flow	hours	-

Table 2.2. Observed effects of NAM parameters by Shamsudin and Hashim (2002)

Parameters	Change	Effects
L_{max}	Increase	Peak runoff decreased Runoff volume reduced
U_{max}	Increase	Peak runoff decreased Runoff volume reduced
CQOF	Increase	Peak runoff decreased Runoff volume increased
TOF	Increase	Peak runoff decreased Runoff volume reduced
CK1 & CK2	Increase	Peak runoff decreased The triangular shape expand horizontally
CKBF	Increase	Base flow decreased
Maximum groundwater depth causing base flow	Increase	Peak runoff decreased Runoff volume reduced

Objective function: In general term, the objective of model calibration can be stated as below: Selection of model parameters so that the model simulates the hydrological behavior of the basin as closely as possible [10]. The question is how is "close"? MIKE-NAM uses multi-objective approach to answer the question. This means that several numerical performance measures are accounted in the optimization process including (1) a good agreement between the average simulated and observed basin runoff volume; (2) a good overall agreement of the shape of the hydrograph; (3) a good agreement of the peak flow with respect to timing, rate and volume; and (4) a good agreement for low flows. For the purpose of flood forecast, in this study, three first objectives were preferred.

Simulation and auto-calibration for each event: Like other conceptual models, the parameters of MIKE-NAM cannot be obtained directly from measurable quantities of basin characteristics [6] and hence model calibration is needed. Using the observed rainfall and evaporation data of each storm event as inputs, model will automatically estimate the optimal set of parameters that best match the computed hydrograph with the observed one at the outlet of the basin. The optimization method used by MIKE-NAM is shuffled complex evolution (SCE) algorithm. The SCE method is a global search method in the sense that it especially designed for locating the global optima of the objective function and not being trapped in local optima.

Calibration for all events: Because the storm events occurred at different time, it is difficult for them to share a common optima set of parameters. Thus, we have to find a set of parameters that is suitable with all events. For this task, we use the trial and error method, the model parameters are changed to match the computed with observed hydrographs of all storm events as much as possible using the rules presented in table 2.2. Our assumption is that the most suitable parameters for all events lie somewhere in the range determined by the optima parameters of each event and therefore, the parameter space for the task of trial-and-error is narrowed.

Verification: According to Refsgaard (1996), a model is said to be validated if its accuracy and predictive capacity in the verification period have been proven to lie within acceptable limits. The verification is implemented by using the new set of observed data and the parameters that have been calibrated in the previous step. Several statistical measures will be adopted to evaluate if the calibrated parameters can reproduce the hydrographs suitable with the observed one, they are:

Correlation coefficient:

$$CC = \frac{Cov(Q_0, Q_s)}{s_{Q_0} s_{Q_s}} \tag{2.1}$$

Peak error: $$PeakErr = \frac{Q_{op} - Q_{sp}}{Q_{sp}} \tag{2.2}$$

Wave error type 1:

$$WaveErr1 = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{Q_{o,i} - Q_{s,i}}{Q_{op}}\right) \tag{2.3}$$

Wave error type 2:

$$WaveErr2 = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{Q_{o,i} - Q_{s,i}}{Q_{o,i}}\right)^2 \tag{2.4}$$

Volume error:

$$VolErr = \frac{\sum_{i=1}^{n}\left(Q_{o,i} - Q_{s,i}\right)}{\sum_{i=1}^{n} Q_{o,i}} \tag{2.5}$$

where Q_{op} and Q_{sp} are observed peak and simulated peak; $Q_{o,i}$ and $Q_{s,i}$ are observed and simulated values at time step i; n is number of time steps.

3. Description of study area

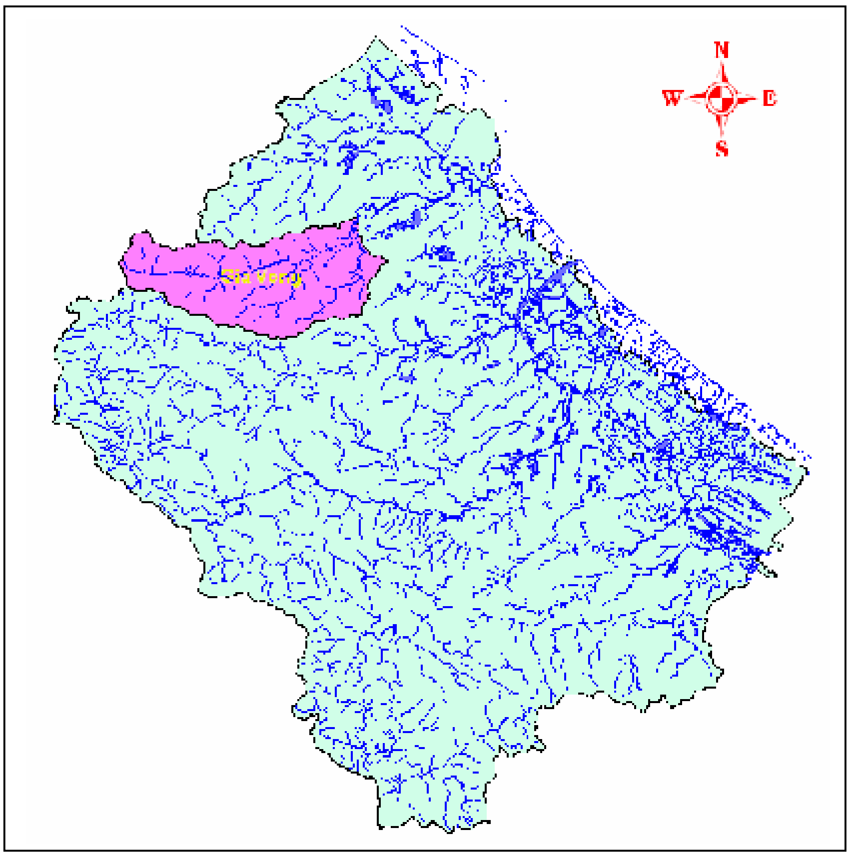


Figure 3.1. Gia Vong basin.

Study area: In order to illustrate for the parameter calibration and verification procedure introduced above, Gia Vong – a river basin in Quang Tri was taken as a case study (Figure 3.1). The basin has an area of about 275 km^2, a perimeter of 111.9 km and an average rainfall of 2500 mm/year.

In Quang Tri, there are a wet and a dry period in a year. The dry period lasts 8 months from January to August, while the wet period lasts 4 month from September to December but heavy rainfall mostly concentrates in the period from September to November (Figure 3.2). The variation in the rainfall and flow of the rivers in Quang Tri has is relatively huge. The wet season makes up around 70% of annual rainfall, causing the severe flooding every year. In the province, there are three main rivers, namely Ben Hai, Thach Han and O Lau. Gia Vong is located at Ben Hai river.

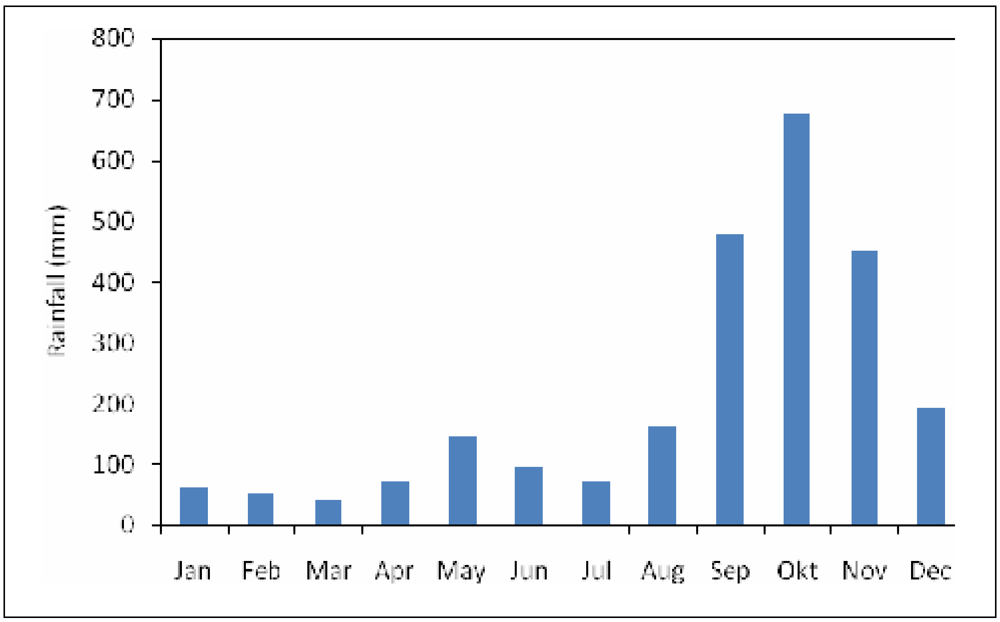


Figure 3.2. Average monthly rainfall at Gia Vong station over the period 1977-2009.

Data available: For this study, rainfall data has been selected from five flooding events occurred in the years 1999, 2004, 2005, 2007 and 2009. The rainfall data were collected at Gia Vong station. The temporal resolution for rainfall is 6 hours. It seems relatively large for a small basin like Gia Vong.

MIKE-NAM requires evaporation data as input for the model. The daily evaporation data at Khe Sanh station were used as inputs for the model. For the model calibration and verification, discharge data is required. The study used hourly data from Gia Vong station at the outlet of the basin. In some periods when hourly data are not available, interpolation technique was applied to generate hourly data.

Initial conditions: Initial conditions represent for the state of the basin at the beginning of the storm event. For the MIKE-NAM, these conditions include the initial relative water contents of surface and root zone storages and initial baseflow. In our study, we changed these values until the computed flow at the beginning of each event is approximately equal to the observed value.

Calibration results: Of five flood events with available data, four events (2004, 2005, 2007 and 2009) were chosen for calibration to find out the best parameter set of NAM model, the remaining event (1999) for testing the consistency of the calibrated parameters. With the auto-calibration method available in NAM model, the best sets of parameters have been made for each event. These optimal parameters are shown in the columns from 2 to 5 of table 3.1. Based on these parameters, the best set of parameters for all calibration events was determined using the trial-and-error method. Compare tables 2.1 and 3.1, we can see that the ranges of parameters reduces noticeably after the auto-calibration step, which makes the trial-and-error much more easily and quickly to find the best parameters for all four storm events.

Table 3.1. Different sets of parameter for MIKE-NAM

Parameter	Best parameters for 2004	Best parameters for 2005	Best parameters for 2007	Best parameters for 2009	Best parameters for all events
Umax	16.5	16.7	18.5	20	18.9
Lmax	175	90	294	298	220
CQOF	0.94	0.98	0.9	0.95	0.94
CKIF	50.88	45	46.98	51.2	50.27
CK1,2	23.8	28	14.5	24.6	23.70
TOF	0.076	0.076	0.883	0.690	0.43
TIF	0.487	0.158	0.466	0.309	0.36
TG	0.84	0.98	0.087	0.005	0.48
CKBF	1270	1127	1602	1067	1267

Tables 3.2 and figures from 3.3 to 3.6 compare the observed and computed hydrographs of four calibration events with the optimal parameters for individual event and for all events. It can be seen that compared to the cases modeled by using the set of parameters for all events, the obtained hydrographs were relatively better when the optimal parameters for each event were applied.

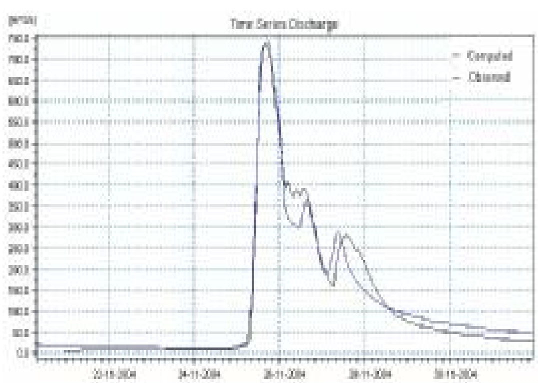
Table 3.2. Results of verification with the optimal parameters for individual event

Statistic criteria	*With the optimal parameters for individual event*				*With the optimal parameters for all events*			
	2004	*2005*	*2007*	*2009*	*2004*	*2005*	*2007*	*2009*
Correlation coefficient	0.978	0.973	0.905	0.919	0.959	0.943	0.842	0.97
Peak error	0.019	0.158	-0.007	-0.115	0.045	0.133	0.001	-0.396
Wave error type 1	0.002	0.002	0.003	0.006	0.002	0.003	0.006	0.007
Wave error type 2	0.064	0.256	0.179	0.149	0.365	0.422	0.249	0.26
Volume error	0.169	0.222	0.292	0.285	0.248	0.29	0.373	0.31

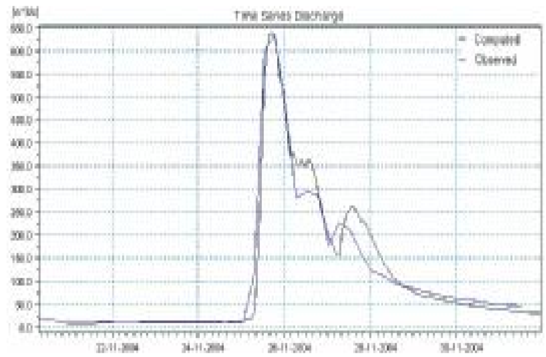
Peak error values are quite good for events 2004 and 2007 and acceptable for event 2005. However, the observed peak flow of event 2009 is considerably higher than the simulated one. This can attributed to the large interval of rainfall data. In this study, we only have rainfall data with interval of 6 hours and thus we never know the distribution of rainfall at the intervals lower than 6 hours, which can be ignore the high intensity values of rainfall. Another reason for this disagreement is the change in the characteristics of Gia Vong basin. The simulated timing to peak is relatively suitable with the observation both single peak and multi-peak events.

The high value of correlation coefficients (greater than 0.84) and small values of wave error type 1 and 2 show that regarding to the shape of the hydrograph, computation estimated in two cases is quite similar to the observation, especially the high flow part.

As for volume, the computed volumes are lower than the observed ones in four events (volume error is positive for all events), causing by the fact that model did not simulate well the low flow part of the hydrograph. Once again, this can be caused by the large time interval of rainfall data.

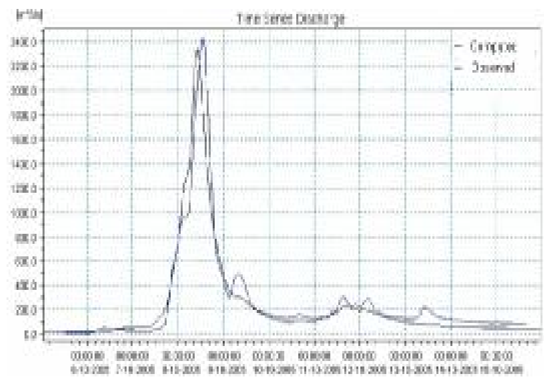


a) With optimal parameters for 2004 event.

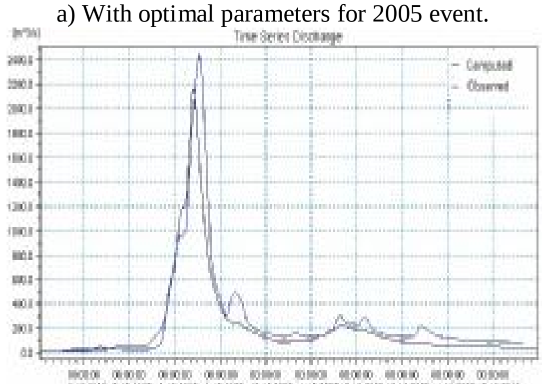


b) With optimal parameters for all events.

Figure 3.3. Simulated 2004-flood hydrograph compared to the observed 2004 flood hydrograph.

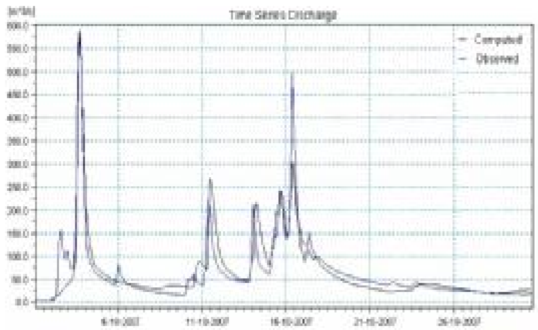


a) With optimal parameters for 2005 event.

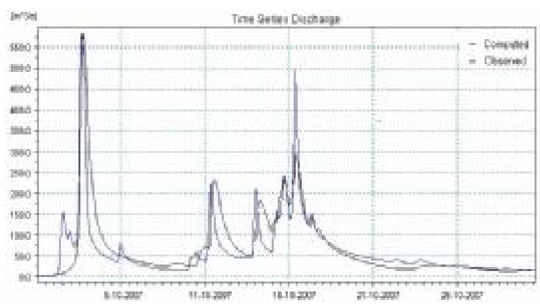


b) With optimal parameters for all events

Figure 3.4. Simulated 2005-flood hydrograph compared to the observed 2005 flood hydrograph.

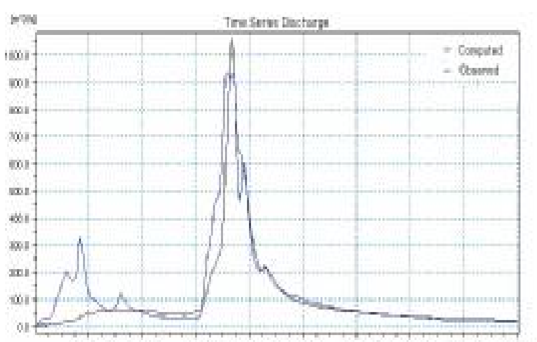


a) With optimal parameters for 2007 event

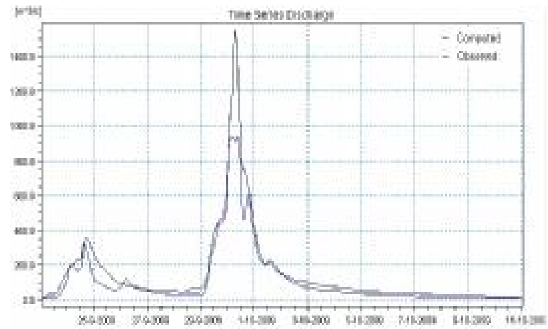


b) With optimal parameters for all events

Figure 3.5. Simulated 2007-flood hydrograph compared to the observed 2007 flood hydrograph.



a) With optimal parameters for 2009 event



b) With optimal parameters for all events

Figure 3.6. Simulated 2009-flood hydrograph compared to the observed 2009 flood hydrograph.

Model verification: Using the parameter set obtained from calibration, MIKE-NAM model has been verified using event November 1999. The statistical measures and simulated and observed hydrographs are shown in Table 3.7 and figure 3.7, respectively. Similar to the calibration stage, the correlation coefficients of two verification flood events are quite great (approximately 0.95). The volume error and wave error type 1 are 0.33 and 0.003, while the difference between computed and observed peak flow is lower than 8%. This proves that the calibration parameter set is consistent, predictive and can be used for estimation of flood frequency from rainfall data.

Table 3.3. Accuracy of the parameters compared to the observed floods for verification stage

Flood	Correlation coefficient	Peak error	Wave error type 1	Wave error type 2	Volume error
1999	0.948	-0.078	0.003	0.412	0.33

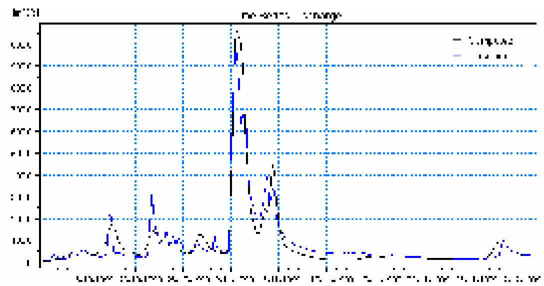


Figure 3.7. Simulated 1999-flood hydrograph compared to the observed 1999 flood hydrograph.

4. Conclusion

This paper introduces a method to calibrate and verify the parameters of hydrological models with the interrupted (event) data. General speaking, the method is the combination of auto-calibration and trial-and-error methods. Auto-calibration is executed to locate the optima sets of parameters for individual storm event by using the SCE algorithm. Then, the trial-and-error method will attempt to find the most suitable parameters for all of the events in the ranges defined by the parameters in the auto-calibration step. This means that the searching parameter space of trial-and-error method is narrowed, supporting to find the best set of parameters of all events quickly. The rainfall-runoff model was adopted in this study is MIKE-NAM model. There are nine main parameters needed to calibrate and verify in this model. Data required by the model include rainfall, evaporation and discharge.

In order to illustrate for the method, Gia Vong river basin in Quang Tri province was selected as a case study. The data are available for five recent large storm events occurring in the year 1999, 2004, 2005, 2007 and 2009 in which event 1999 was used for verification and the remaining events were used for calibration. First of all, sets of parameters were individually estimated for each of four calibration events. After that, the most suitable parameters for all events were chosen within the range defined by four parameter sets in the previous step. With the support of auto-calibration method, the ranges of parameters decreased considerably compared to the original ranges, helping the trial-and-error more quickly and easily to find the best parameters for all events. The results show the good agreements of the hydrograph shape and total flow volume between simulation and observation for all four calibration events. The peak flow simulation is quite good for event 2004 and 2007 and acceptable for event 2005. However, the peak flow of observation is much higher than that of simulation. This can be attributed to both of the large interval of rainfall data and the changes of basin characteristics. The calibrated parameters were afterward verified using data from 1999 flood event. The good agreement of the verification results indicate that the parameters are consistent, predictive and can be applied for different purposes such as flood forecast, water resources planning and management.

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