INVESTIGATION BEST NUMBER OF TANKS FOR HYDROLOGICAL TANK MODEL FOR RURAL CATCHMENT IN HUMID REGION

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ABSTRACT

Hydrological Tank model has proven more capable than many other models in modeling the hydrologic responses from a wide range of humid watershed. Many hydrologists are using this model due to its simplicity of concept and computation while achieving forecasting accuracy comparable with more sophisticated models. Throughout the years, various types of Tank model have been developed. The best was found to be storages series type. However, there is no general agreement regarding the best number of series storage tanks for rural catchment in humid region. In this study, three types of series storage tanks were selected to model the daily and hourly runoff for Bedup Basin, a rural catchment in humid region. These three Tank models that consist of three, four and five series storages tanks are named as 3-Tank-D, 4-Tank-D, 5-Tank-D respectively for daily model, and 3-Tank-H, 4-Tank-H, 5-Tank-H respectively for hourly model. The model performance is evaluated with coefficient of correlation (R) and Nash-sutcliffe coefficient (E^2). Results revealed that the best number of tank is four, where average R and E^2 yield to 0.6833 and 0.6620 respectively for daily runoff simulation, 0.8985 and 0.8214 respectively for hourly runoff simulation. Besides, sensitivity analysis also demonstrated the infiltration coefficient from forth to fifth tank (C9) has minor impact to runoff peak discharge and side outlet coefficient for fifth tank (C10) doesn't have any significant impact to runoff peak discharge for both daily and hourly runoff simulation. Thus, these two parameters can be ignored. This result further confirmed that the best number of tanks for daily and hourly runoff simulation for rural catchment in humid region is four.

Keywords: *Coefficient of Correlation (R), Conceptual Rainfall-runoff Model, Hydrological Tank Model, Nash-Sutcliffe Coefficient (E^2)*

1.0 INTRODUCTION

Hydrologic Tank model, a conceptual rainfall-runoff (CRR) model, was developed by Sugawara and Funiyuki (1956)[1]. It consists of a set of linear storages in series or parallel with side and bottom outlets. This CRR model presents the complicated and nonlinearity of rainfall-runoff processes through interconnected storages and simple equations to represent the water movement among the storages tanks.

Tank model has proven more capable than many other models in modeling the hydrologic responses from a wide range of humid watershed. Many hydrologists are using this model [2-5] due to its simple analytical structure and computation while achieving forecasting accuracy comparable with more sophisticated models. Department of Irrigation and Drainage Malaysia (DID) [6] used Tank model to forecast flood levels of the Kelantan River at the Guillemard Bridge during the Northeast Monsoon. Huang *et al.* (2006)[7] applied Tank model for application of middleware technique in web of flood forecasting System of Gan River, JiangXi province, China. Sothea *et al.* (2006)[8] applied the "3*4+1" type Tank model to calculate the runoff of the Lower Mekong River Basin from Chiang Saen to Kompong Cham and its sub catchments at Mekong Delta, Cambodia. Besides, Chen and Barry (2006)[9] coupled semidistributed Tank model with ANNs to explore the nonlinear transformation of the runoff generated from the individual subcatchments into the total runoff at the entire Miyun reservoir outlet, Beijing, China. However, Tank model is not designed to use parameters that are directly measured in field. Their parameters are usually obtained by calibration.

Prior conducting the calibration process, the structure and the best number of tanks for Hydrological Tank model for the study area need to be determined. The determination of best number of tanks will ensure and lead to the best fit between the observed and estimated flow hydrograph. As review back the history of Tank model, Sugawara (1957)[10] had developed various types of Tank model to derive discharge from precipitation. Among the types of Tank model developed are a) Exponential Type, b) Parallel Exponential Type, c) Overflow Type, d) Storage Type and e) Series Storage Type. Sugawara (1957)[10] proclaimed that the best type of model was the series storage type Tank model.

The original development of the model was based on the assumption that two water storage tanks were required to represent both surface runoff and intermediate runoff. Despite the original Tank model is generally considered to be lacking of physical meaning, as the model undergoes various developments, the physics of the model has been enhanced. The evolution of the Tank model has occurred over decades and variations of the model have been proposed.

In the subsequent development of the model (Sugawara 1967)[2], four storages tank were introduced. According to this configuration, runoff generated from side outlets of the top tank is considered as surface runoff, runoff from the second tank as intermediate runoff, whereas runoff generated from the side outlets of the third and fourth tanks are referred to subbase runoff and base flow, respectively.

Besides, Sugawara (1974)[11] also proposed the 4*4 type Tank model to be applied for the watershed having dry season. The model also modified by Sothea *et al.* (2006)[3] to form the “3*4+1” type Tank model to forecast the flow at Lower Mekong River Basin, Cambodia. Meanwhile, Sugawara (1984)[4] also further developed the Tank model with including the snow component. In an attempt to consider variations in soil moisture content especially in the arid or semiarid areas, additional structures were added to the bottom layer of the top tank to represent effect of the primary and secondary soil moisture storage [5].

Meanwhile, Cooper *et. al.* (1997 and 2007)[12, 13] had calibrated 2-Tank series storage type to simulate runoff in Canada. A simple 2-Tank model with an upper and lower tank was also used by Chen and Barry (2006)[9] for simulating surface and groundwater generation. Concurrently, used four-layered Tank model for simulating runoff in their respective studies [14-21].

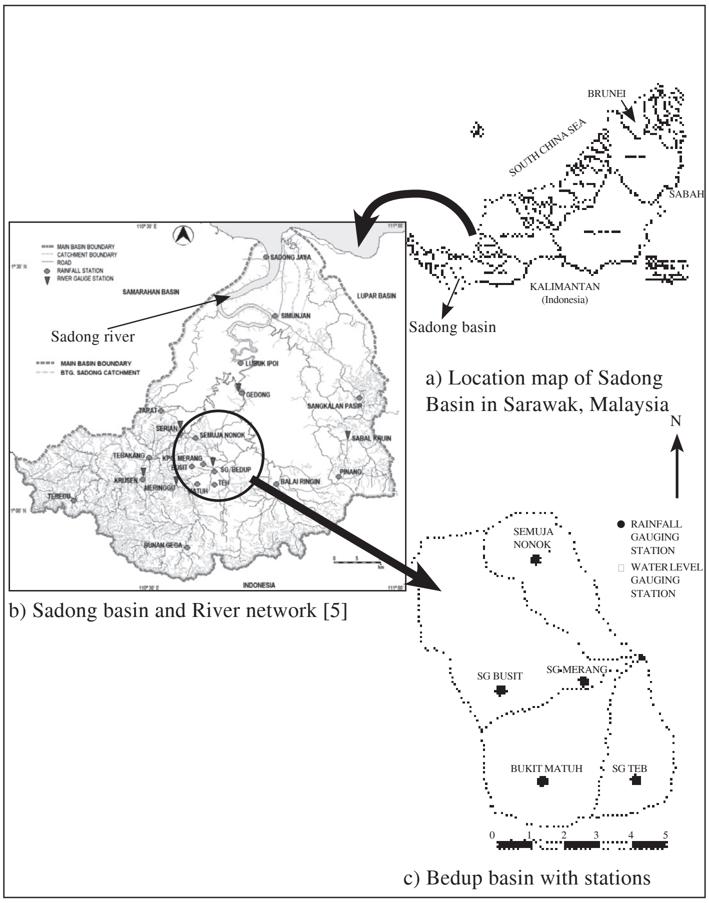
From that above statement, there is no general agreement among the researchers the best and appropriate number of tanks for simulating runoff accurately. Therefore, the present study was undertaken to determine the best number of tanks of Tank model that provide reliable and accurate estimates of runoff for rural catchment in humid region. Manual trial and error method is selected for Tank model calibration.

2.0 STUDY AREA

The selected study area is Sungai Bedup Basin in humid region. It is located at upper stream of Batang Sadong where tidal is unreachable. The basin area is approximately 47.5 km^2 and the elevation varies from 8m to 686m above mean sea level [22]. The vegetation cover is mainly of shrubs, low plant and forest. Sungai Bedup’s basin has a dendritic type channel system. The maximum stream length for the basin is approximately 10km, which is measured from the most remote area point of the stream to the basin outlet.

This basin is selected as there are five rainfall stations within the catchment and a water level stations at basin outlet. The historical long series, good quality rainfall and water level data are available since 1977. Moreover, the rating curve for Bedup Basin is available from Department of Irrigation and Drainage (DID) Sarawak [6].

The locality plan of Sungai Bedup Basin was presented in Figure 1. Figure 1a shows the location of Sadong Basin. Main boundary of the Sadong Basin, rainfall and river stage gauging stations within Sadong Basin, are shown in Figure 1b. Figure 1c presents the 5 rainfall gauging stations available in Sungai Bedup Basin, namely, Bukit Matuh (BM), Semuja Nonok (SN), Sungai Busit (SB), Sungai Merang (SM) and Sungai Teb (ST), and one river stage gauging station at Sungai Bedup located at the outlet of the basin.



a) Location map of Sadong Basin in Sarawak, Malaysia

b) Sadong basin and River network [5]

c) Bedup basin with stations

Figure 1: Locality map of Bedup basin, sub-basin of Sadong basin, Sarawak, Malaysia

For Tank model calibration, the input data used are weighted areal daily or hourly rainfall data obtained from Thiessen Polygon Analysis. The daily or hourly rainfall data from the 5 rainfall stations are processed, formatted and fed into the Thiessen Polygon analysis worksheet to calculate an weighted areal rainfall throughout the catchment. The area weighted precipitation for BM, SN, SB, SM, ST are found to be 0.17, 0.16, 0.17, 0.18 and 0.32 respectively. The weighted areal daily or hourly rainfall data for that time step is then fed into the Tank model. The calibrated Tank model will then carry out computations to simulate the daily or hourly discharges for Bedup Outlet.

3.0 SELECTION NUMBER OF TANKS

Since different catchment required different number of tanks for flow simulation, it is important to find the most suitable and appropriate Tank model for the study catchment. Through preliminary study, 2-Tank model was found unable to simulate runoff accurately for rural catchment in humid region. Thus, the investigation of 2-Tank model was not presented in this study. 3 types of series storage Tank models selected for manual calibration are named as 3-Tank, 4-Tank and 5-Tank. Specifically, 3-Tank-D, 4-Tank-D, 5-Tank-D for daily runoff simulation and 3-Tank-H, 4-Tank-H, 5-Tank-H for hourly runoff simulation. The schematic diagrams for investigated 3-Tank, 4-Tank and 5-Tank models are presented in Figures 2, 3 and 4 respectively. The complexity of Tank model increased as the number of tanks increased from 3 to 5. 10 parameters need to be calibrated for 3-Tank model are named as C1, C2, C3, C4, C5, C6, X1, X2, X3 and X4. Meanwhile, the parameters calibrated for 4-Tank model are C1, C2, C3, C4, C5, C6, C7, C8, X1, X2, X3, X4 and X5. Besides, 16 parameters are calibrated for 5-Tank model namely C1, C2, C3, C4, C5, C6, C7, C8, C9, C10, X1, X2, X3, X4, X5 and X6. However, the values for X3, X4, X5 and X6 always found to be 0 through preliminary study. Thus, these parameters are not calibrated for investigation of best number of tank for rural catchment in humid region. The description of Tank model parameters are presented in Table 1.

Table 1: Description of tank model parameters

Parameters	Description
C1	Site outlet coefficient No.1 for first tank
C2	Site outlet coefficient No.2 for first tank
C3	Infiltration coefficient from first tank to second tank
C4	Site outlet coefficient for second tank
C5	Infiltration coefficient from second to third tank
C6	Site outlet coefficient for third tank
C7	Infiltration coefficient from third to forth tank
C8	Site outlet coefficient for forth tank
C9	Infiltration coefficient from forth to fifth tank
C10	Site outlet coefficient for fifth tank
X1	Height of side outlet No.1 for first tank
X2	Height of side outlet No.2 for first tank
X3	Height of side outlet for second tank
X4	Height of side outlet for third tank
X5	Height of side outlet for forth tank
X6	Height of side outlet for fifth tank

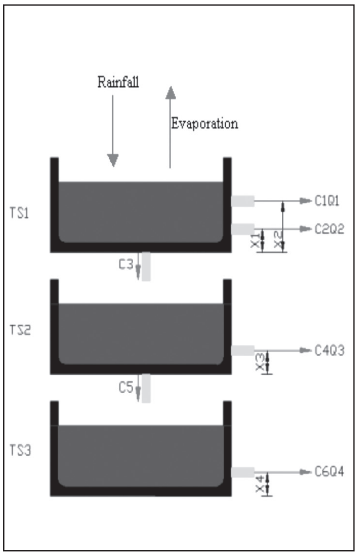


Figure 2: Schematic diagram of 3-Tank model

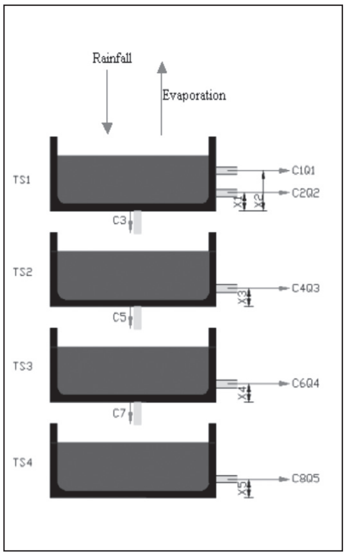


Figure 3: Schematic diagram of 4-Tank model

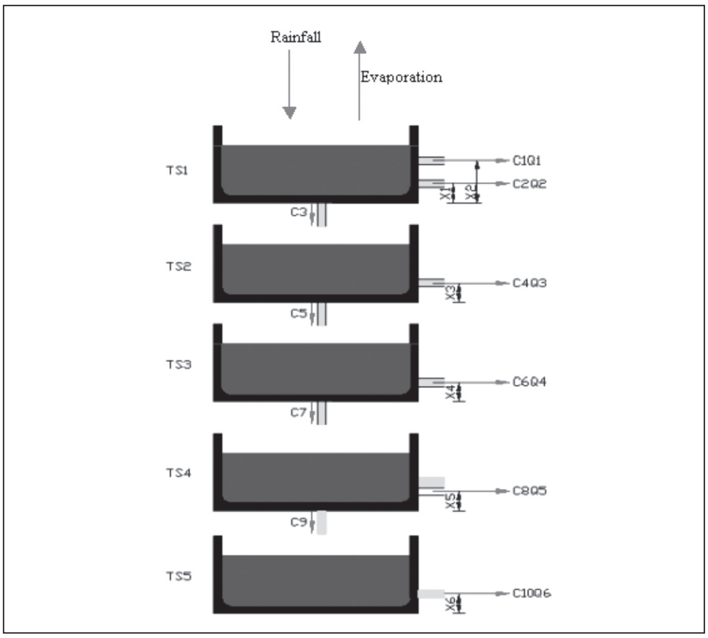


Figure 4: Schematic diagram of 5-Tank model

4.0 METHODOLOGY

4.1 Model Development and Learning Mechanism

In general, the model development for both daily and hourly runoff simulation can be categorised into calibration stage and validation stage. During calibration stage, a pair of rainfall runoff data was calibrated to search for the optimal parameters through trial and error method. The optimal parameters obtained are validated using different pairs of rainfall-runoff data to ensure the parameters obtained will provide the best fit between the observed and simulated runoff.

Daily rainfall-runoff data from January to March 2000 in Table 1 is used for model calibration. The optimal parameters obtained are then validated with three different pairs of daily rainfall-runoff data dated April to June 2000, July to September 2000 and October to November 2000 as tabulated in Table 2.

Table 2: Daily calibration and validation data used for determining best number of tanks

Item	Data Period	Data Description
1	Jan to Mar 2000	Calibration
2	Apr to Jun 2000	Validation
3	Jul to Sep 2000	Validation
4	Oct to Nov 2000	Validation

Similarly for hourly Tank model calibration and validation, the optimal number of tank was calibrated and validated using the data as shown in Table 3. Hourly data from 1 to 7 January 1999 in Table 3 is used for model calibration. The validation data used are Items 2 to 8 as presented in Table 2.

Table 3: Hourly calibration and validation data used for determining best number of tanks

Item	Data Period	Data Description
1	1-7 Jan 99	Calibration
2	5-8 Apr 99	Validation
3	5-8 Feb 99	Validation
4	8-12 Aug 98	Validation
5	9-12 Sep 98	Validation
6	15-18 Mar 99	Validation
7	20-24 Jan 99	Validation
8	26-31 Jan 99	Validation

4.2 Sensitivity Analysis

Sensitivity analysis is important for better understanding and estimating values and thus reduced uncertainty [23]. Knowing the sensitivity of parameters can also reduced the time spent on the non-sensitive one. Therefore, sensitivity analysis is an technique used for the assessment of the input parameters with respect to their impact on model output, which is useful not only for model development, but also for model validation and reduction of uncertainty[24].

In this study, sensitivity analysis is conducted for 3-Tank, 4-Tank and 5-Tank models for both daily and hourly runoff simulation. The parameters investigated for 3-Tank model are C1, C2, C3, C4, C5, C6, X1 and X2. Meanwhile, the sensitivity for C1, C2, C3, C4, C5, C6, C7, C8, X1 and X2 are investigated for 4-Tank model. Subsequently, 12 parameters named as C1, C2, C3, C4, C5, C6, C7, C8, C9, C10, X1 and X2 are investigated for 5-Tank model.

While conducting the sensitivity analysis, the parameter investigated is changing from ±5%, ±10%, ±20%, ±30%, ±50% to ±75%, while the other parameters are remained constant. The effect of each parameters investigated to model outputs are recorded. The sensitivity for daily runoff is analysed based on coefficient of correlation (R) and Nash-Sutcliffe coefficient (E^2) values, whereas sensitivity analysis for hourly runoff is based on the runoff peak discharge.

4.3 Performance Criteria

R and E^2 will measure the overall differences between the simulated and observed runoff. R and E^2 values of 1.0 implies a perfect fit. The formulas of these two coefficients are given in Table 4.

Table 4: Statistics for model comparison

Coefficient	Symbol	Formula
Coefficient of Correlation	R	$\frac{\sum(obs-\overline{obs})(pred-\overline{pred})}{\sqrt{\sum(obs-\overline{obs})^2\sum(pred-\overline{pred})^2}}$
Nash-Sutcliffe Coefficient	E^2	$E^2 = 1 - \frac{\sum_{i}^{j}(obs-pred)^2}{\sum_{k^i}^{j}(obs-\overline{obs})^2}$

where obs = observed value, pred = predicted value, $\overline{obs}$ = mean observed values, $\overline{pred}$ = mean predicted values and j = number of values.

Besides, the formula for peak discharge is presented is Equation 1.

$$\mathit{runoff\_peak\_discharge} = \frac{\mathit{simulated\_peak\_observed\_peak}}{\mathit{observed\_peak}} \times 100\% \qquad (1)$$

5.0 RESULTS AND DISCUSSION

5.1 Determination Number of Tank for Daily Runoff

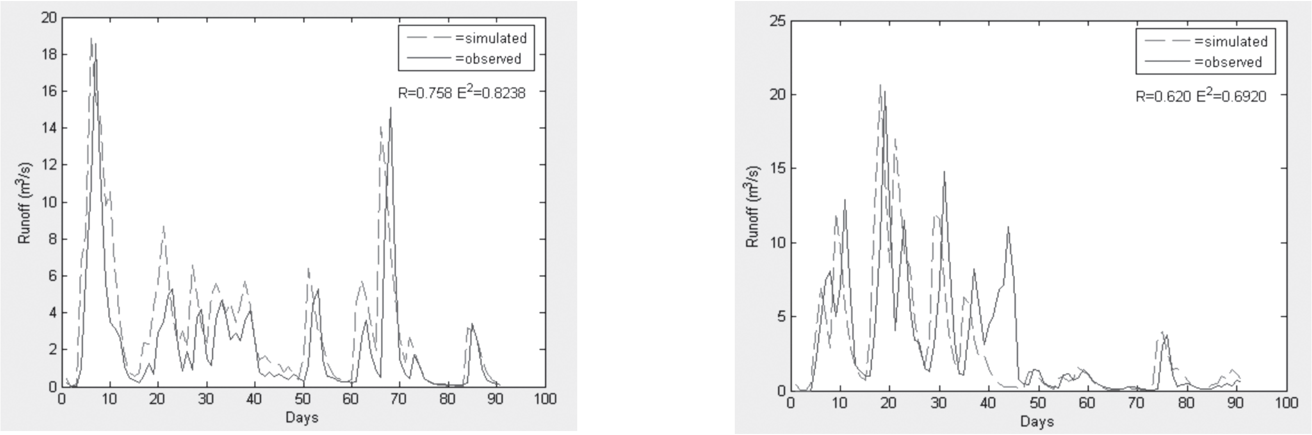
Table 5 shows the optimum parameters obtained for 3-Tank-D, 4-Tank-D and 5-Tank-D using trial and error method. The performance of different configuration of Tank model as validated with three different time periods is presented in Table 6. Figure 5 presents comparison between observed and simulated runoff for 4-Tank-D Model using optimal parameters that calibrated through trial and error method.

Table 5: Optimum parameters calibrated for different configuration of Tank models

Parameters	3-Tank-D Model	4-Tank-D Model	5-Tank-D Model
C1	0.001	0.001	0.001
C2	0.002	0.002	0.002
C3	0.34	0.42	0.62
C4	0.0005	0.055	0.055
C5	0.6	0.6	0.6
C6	0.05	0.055	0.05
C7	-	0.83	0.83
C8	-	0.000001	0.00001
C9	-	-	0.00001
C10	-	-	0.00001
X1	10.00	10.00	10.00
X2	20.00	20.00	20.00

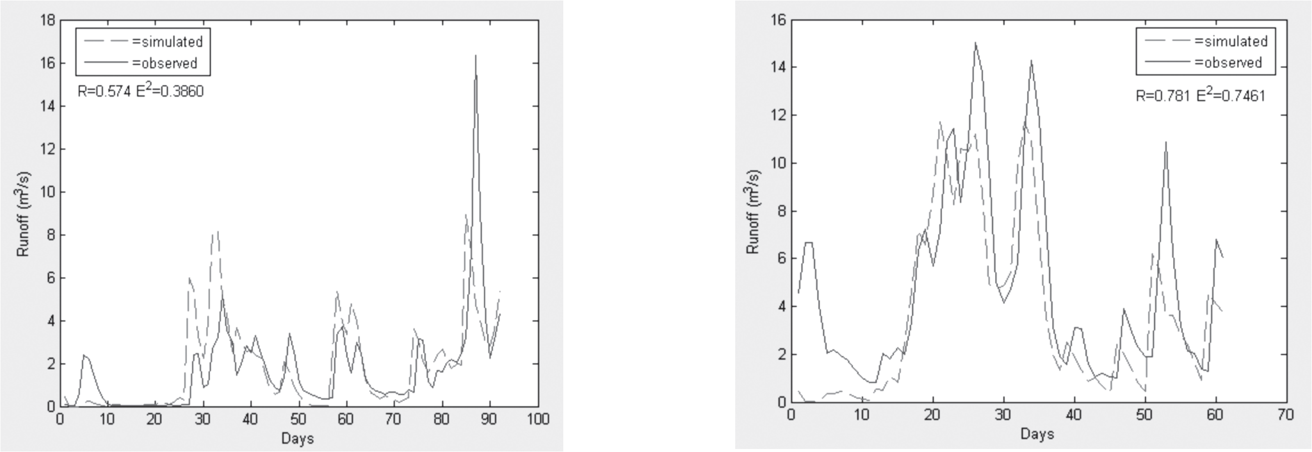
Table 6: Performance of different tank models validated with different data

Tank Configuration	Data Period	R	E^2
3-Tank-D Model	Jan to Mar 2000	0.714	0.7675
	Apr to Jun 2000	0.565	0.5803
	Jul to Sep 2000	0.511	0.3659
	Oct to Nov 2000	0.744	0.5510
Average		0.6335	0.5662
4-Tank-D Model	Jan to Mar 2000	0.758	0.8238
	Apr to Jun 2000	0.620	0.6920
	Jul to Sep 2000	0.574	0.3860
	Oct to Nov 2000	0.781	0.7461
Average		0.6833	0.6620
5-Tank-D Model	Jan to Mar 2000	0.714	0.7670
	Apr to Jun 2000	0.566	0.5794
	Jul to Sep 2000	0.512	0.2767
	Oct to Nov 2000	0.738	0.5845
Average		0.6325	0.5519



(a) Calibration Data from Jan 2000 to Mar 2000

(b) Validation Data from Apr 2000 to Jun 2000



(c) Validation Data from Jul 2000 to Sep 2000

(d) Validation Data from Oct 2000 to Nov 2000

Figure 5: Comparison between observed and simulated runoff for 4-Tank-D model using optimal parameters calibrated manually

The average R and E^2 obtained for 3-Tank-D model through manual calibration are recorded as 0.6335 and 0.5662 respectively, with configuration of X1=10, X2=20, C1=0.001, C2=0.002, C3=0.34, C4=0.0005, C5=0.6 and C6=0.05. The simulation result is improved significantly using 4-Tank-D model where average R and E^2 yield to 0.6833 and 0.6620 respectively with the configuration of X1=10, X2=20, C1=0.001, C2=0.002, C3=0.42, C4=0.055, C5=0.6, C6=0.055, C7=0.83 and C8=0.000001. As the Tank model is further investigated using 5-Tank-D, the performance of 5-Tank-D model is slightly decreased to average R=0.6325 and E2=0.5519. The optimal configuration for 5-Tank-D model were found to be X1=10, X2=20, C1=0.001, C2=0.002, C3=0.62, C4=0.055, C5=0.6, C6=0.05, C7=0.83, C8=0.000001, C9=0.000001 and C10=0.000001. It was found that the parameters C9 and C10 for 5-Tank-D Model are not improving the simulation results. Moreover, the optimum C9 and C10 values obtained through trial and error method are very small where both are depicted as low as 0.00001. Hence, it is concluded that the best number of tanks for simulating daily runoff in this study is 4 (4-Tank-D Model).

5.2 Sensitivity Analysis for Daily Runoff

Sensitivity analysis was conducted for 3-Tank-D, 4-Tank-D and 5-Tank-D models, to determine the effect and impact each of the parameters to model output in terms of R and E^2.

5.2.1 Sensitivity Analysis for 3-Tank-D Model

Figure 6 illustrates the results of sensitivity analysis of 3-Tank-D Model for R and E^2 values.

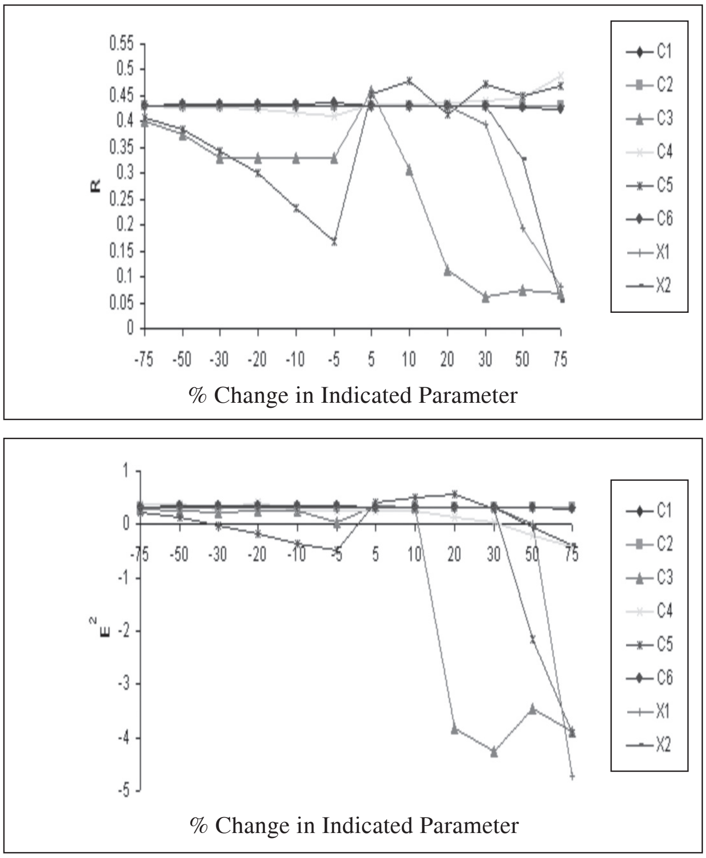


Figure 6: Sensitivity analysis of 3-Tank-D model for R values

From the results of sensitivity analysis, it appears that the change of C1 and C2 from 75% to –75% didn't affect the accuracy of the simulation results. Besides, the accuracy of the simulation results is slightly affected by parameters C4 and C6 as these two parameters changed from 75% to –75%. The infiltration parameters C3 and C5 have significant impact to the accuracy of the simulation results. Meanwhile, X1 and X2 were found not affecting the accuracy of simulation results as these two parameters changed from –75% to 30%. However, the simulation results were decreased significantly as X1 and X2 values increased to 50% and 75%.

5.2.2 Sensitivity Analysis for 4-Tank-D Model

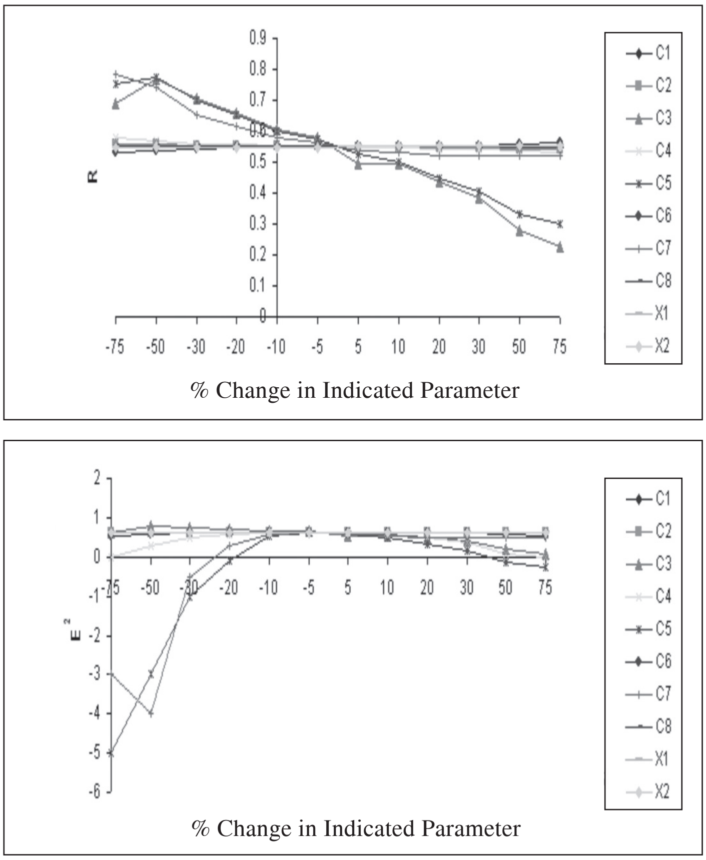


Figure 7: Sensitivity analysis of 4-Tank-D model for R and E^2 values

Sensitivity analysis for 4-Tank-D (illustrated in Figure 7) presents that parameters C1, C2, C6, C8, X1 and X2 didn't affect the simulation results significantly as these parameters changed from –75% to 75%. However, the infiltration parameters C3, C5 and C7 did show great impact to the accuracy of simulation results as these coefficients changed from –75% to 75%. Meanwhile, side outlet coefficient C4 has also affected the E^2 result with the changes of C4 from –75% to 75%.

5.2.3 Sensitivity Analysis for 5-Tank-D Model

The results of sensitivity analysis of 5-Tank-D Model for R and E2 values are illustrated in Figure 8. The results show that parameters C1, C9 and C10 are not sensitive to the change from 75% to –75%. Coefficient C2, C6, C8, X1 and X2 are slightly affecting the accuracy of the simulation results with the change from 75% to –75% of these parameters. Meanwhile, parameters C3, C4, C5 and C7 had significant impact to the simulation results as these parameters changed from 75% to –75%.

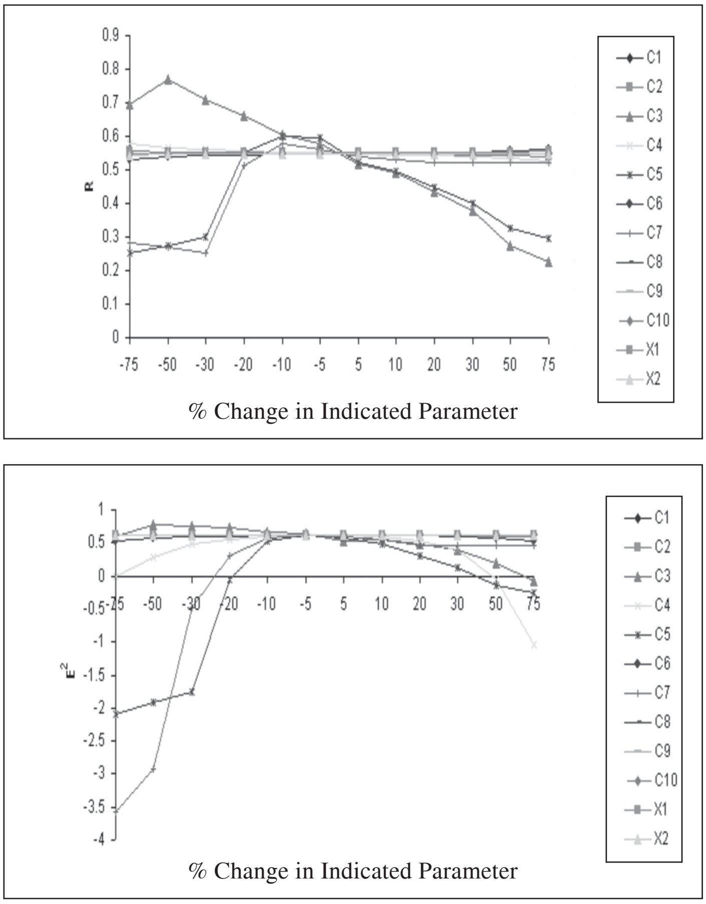


Figure 8: Sensitivity analysis of 5-Tank-D model for R and E^2 values

Since the result show that both C9 and C10 don't have any impact to simulation results, these two parameters which are the infiltration coefficient from forth to fifth tank and side outlet coefficient for fifth tank respectively, can be ignored. Therefore, it is concluded that the best number of tank for daily runoff simulation for Bedup Basin is four.

5.3 Determination Number of Tanks for Hourly Runoff

Three configurations of Tank model are investigated for hourly runoff simulation, named as 3-Tank-H, 4-Tank-H and 5-Tank-H. The optimum parameters obtained for 3-Tank-H, 4-Tank-H and 5-Tank-H models calibration are presented in Table 7. Table 8 shows the performance of 3-Tank-H, 4-Tank-H and 5-Tank-H when simulating 8 separate storm events using optimal parameters obtained. Figure 9 presents comparison between observed and simulated runoff for 4-Tank-H Model using optimum parameters obtained.

For hourly runoff simulation, all 3-Tank-H, 4-Tank-H and 5-Tank-H are able to simulate hourly runoff accurately. The optimal parameters obtained for 3-Tank-H model are C1 = 0.01, C2 = 0.002, C3 = 0.1, C4 = 0.01, C5 = 0.08, C6 = 0.05, X1 = 10 and X2 = 30, where average R and E^2 yield to 0.8916 and 0.7492 respectively. It was found that the performance of Tank model is slightly increased as the number of tank increased from 3 to 4.

Table 7: The optimum parameters calibrated for different configuration of tank models

Parameters	3-Tank-H Model	4-Tank-H Model	5-Tank-H Model
C1	0.010	0.010	0.001
C2	0.002	0.002	0.002
C3	0.100	0.100	0.070
C4	0.010	0.010	0.020
C5	0.080	0.080	0.040
C6	0.050	0.050	0.050
C7	-	0.030	0.030
C8	-	0.050	0.050
C9	-	-	0.030
C10	-	-	0.002
X1	10	10	10
X2	30	40	40

Table 8: The performance of different configuration of tank model

Tank Configuration	Data Period	R	E^2
3-Tank-H Model	1-7 Jan 99	0.945	0.8560
	5-8 Apr 99	0.891	0.3901
	5-8 Feb 99	0.864	0.7586
	8-12 Aug 98	0.743	0.7720
	9-12 Sep 98	0.984	0.8772
	15-18 Mar 99	0.978	0.9473
	20-24 Jan 99	0.836	0.8532
	26-31 Jan 99	0.892	0.5388
Average		0.8916	0.7492
4-Tank-H Model	1-7 Jan 99	0.946	0.8399
	5-8 Apr 99	0.916	0.5096
	5-8 Feb 99	0.857	0.8979
	8-12 Aug 98	0.776	0.8387
	9-12 Sep 98	0.971	0.9701
	15-18 Mar 99	0.977	0.9851
	20-24 Jan 99	0.853	0.8966
	26-31 Jan 99	0.892	0.6331
Average		0.8985	0.8214
5-Tank-H Model	1-7 Jan 99	0.947	0.8552
	5-8 Apr 99	0.891	0.3901
	5-8 Feb 99	0.864	0.7553
	8-12 Aug 98	0.743	0.7720
	9-12 Sep 98	0.986	0.8727
	15-18 Mar 99	0.979	0.9456
	20-24 Jan 99	0.836	0.8531
	26-31 Jan 99	0.892	0.5388
Average		0.8923	0.7479

The average R and E^2 were found improved to 0.8985 and 0.8214 respectively with the configuration of C1 = 0.01, C2 = 0.002, C3 = 0.1, C4 = 0.01, C5 = 0.08, C6 = 0.05, C7 = 0.03, C8 = 0.05, X1 = 10 and X2 = 40. Besides, the best configuration obtained for 5-Tank-H model are C1 = 0.001, C2 = 0.002, C3 = 0.07, C4 = 0.02, C5 = 0.04, C6 = 0.05, C7 = 0.03, C8 = 0.05, C9 = 0.03, C10 = 0.002, X1 = 10 and X2 = 40.

However, the performance of 5-Tank-H model is slightly decreased with average R=0.8923 and E^2=0.7479. This reflected that the optimum numbers of Tank model for hourly runoff calibration is 4 (4-Tank-H model) for Bedup Basin.

5.4 Sensitivity Analysis for Hourly Runoff

Sensitivity Analysis was conducted for 3-Tank-H, 4-Tank-H and 5-Tank-H models. The aim is to determine the effect and impact each of the parameters to runoff peak discharge.

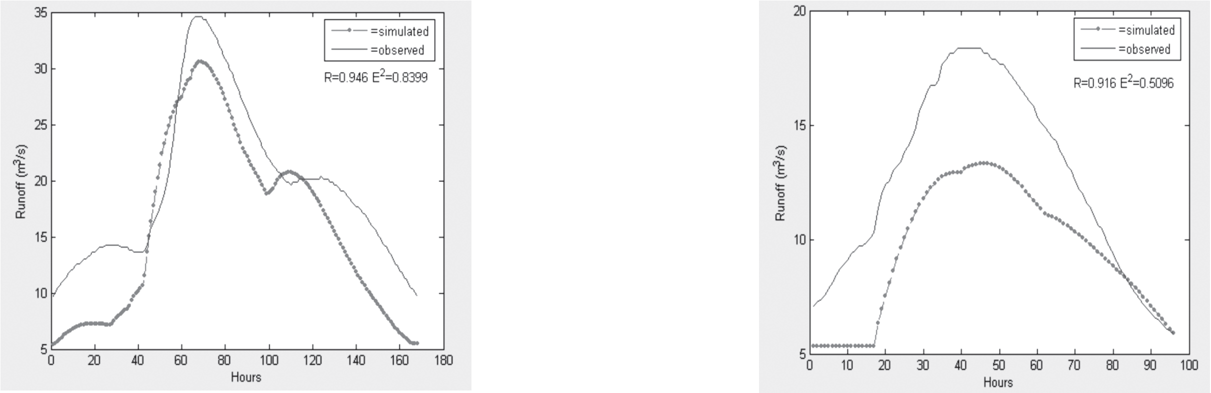
5.4.1 Sensitivity Analysis for 3-Tank-H Model

The result of sensitivity analysis of 3-Tank-H Model for Runoff Peak Discharge was illustrated in Figure 10. From the results of sensitivity analysis, it appears that the change of C1 and C2 from 75% to –75% didn't affect the runoff peak discharge. Besides, it was also observed that the parameter C4, X1 and X2 also not affecting the runoff peak discharge much. However, the sensitivity analysis shows that the infiltration coefficient C3, C5 and side outlet coefficient C6 are the three dominant parameters that control the runoff peak discharge. The results show that these three parameters have significant impact to the runoff peak discharge as these three parameters change from 75% to –75%.

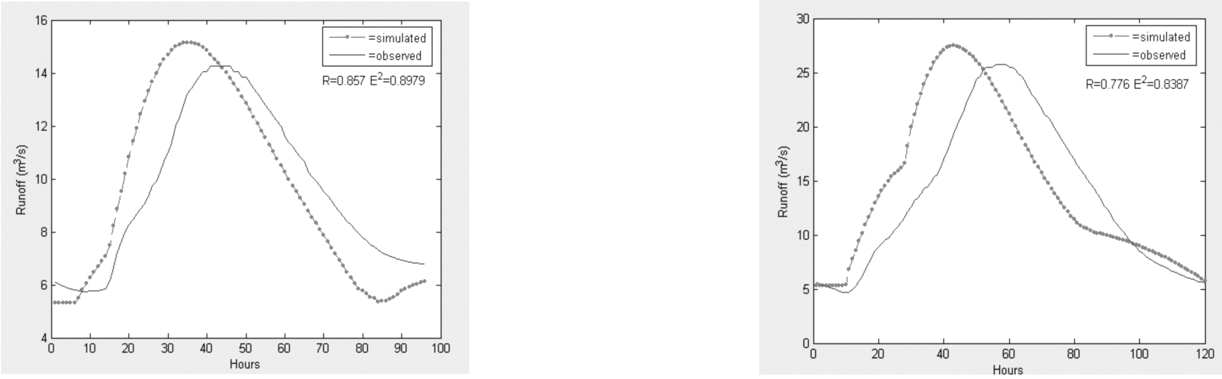
5.4.2 Sensitivity Analysis for 4-Tank-H Model

Figure 11 presents the results of sensitivity analysis of 4-Tank-H Model for runoff peak discharge. Sensitivity analysis for 4-Tank-H illustrates that parameters C1, C2, C7, X1 and X2 are not sensitive to the runoff peak discharge as these parameters change from –75% to 75%. Meanwhile, parameter C4 has minor effect to the runoff peak discharge. However, the results show that the four main parameters that controlled the runoff peak discharge are C3, C5, C6 and C8.

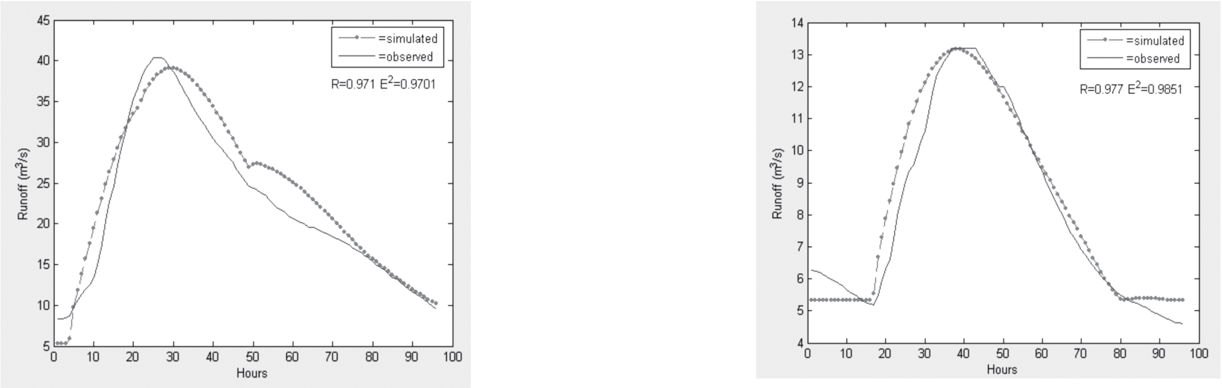
These four parameters did show great impact to the runoff peak discharge as the coefficients changed from –75% to 75%.



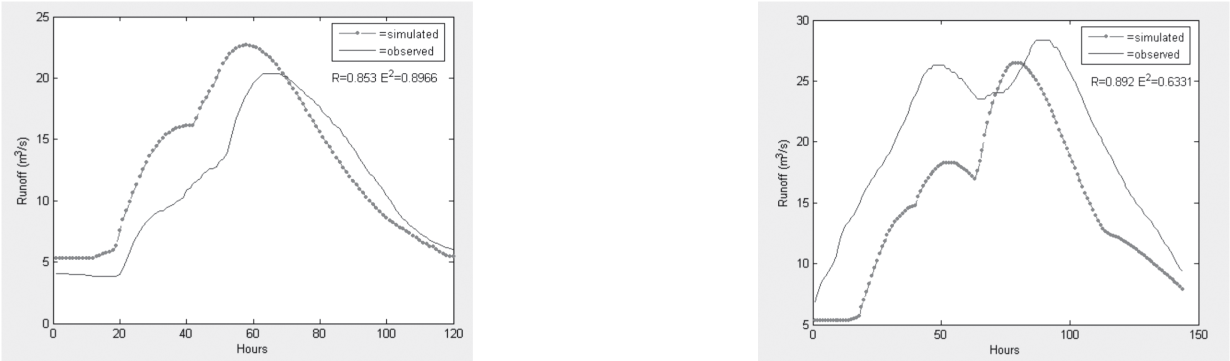
(a) Calibration data from 1 Jan 1999 to 7 Jan 1999 (b) Validation data from 5 Apr 1999 to 8 Apr 1999



(c) Validation data from 5 Feb 1999 to 8 Feb 1999 (d) Validation data from 8 Aug 1998 to 12 Aug 1998



(e) Validation data from 9 Sep 1998 to 12 Sep 1998 (f) Validation data from 15 Mar 1999 to 18 Mar 1999



(g) Validation data from 20 Jan 1999 to 24 Jan 1999 (h) Validation data from 26 Jan 1999 to 31 Jan 1999

Figure 9: Comparison between observed and simulated runoff for 4-Tank-H model using optimum parameters obtained

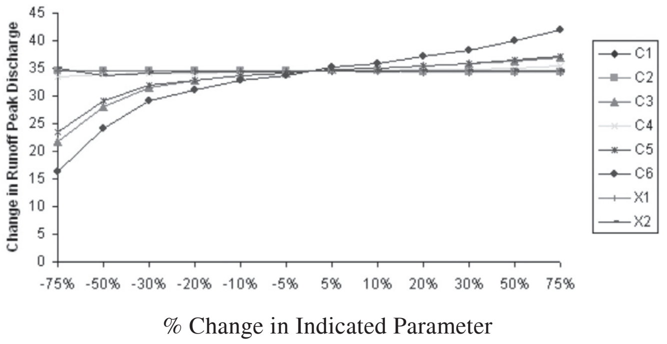


Figure 10: Sensitivity analysis of 3-Tank-H model for runoff peak discharge

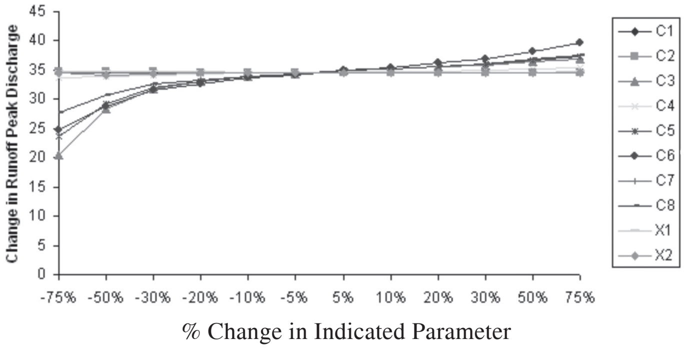


Figure 11: Sensitivity analysis of 4-Tank-H model for runoff peak discharge

5.4.3 Sensitivity Analysis for 5-Tank-H Model

The results of sensitivity analysis of 5-Tank-H Model for runoff peak discharge are illustrated in Figure 12. The results show that parameters C1, C2, C10, X1 and X2 do not affect the runoff peak discharge as these coefficients change from 75% to –75%. It was observed that coefficients C7 and C9 have minor impact to the runoff peak discharge as these values change from -75% to 75%. Results also show that five major coefficients that are controlling the runoff peak discharge are C3, C4, C5, C6 and C8.

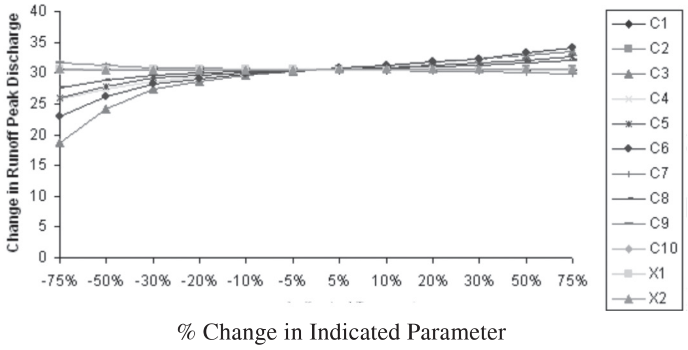


Figure 12: Sensitivity analysis of 5-Tank-H model for runoff peak discharge

As the result show that C9 has minor impact to runoff peak discharge and C10 doesn't have any impact to runoff peak discharge, these two parameters which are the infiltration coefficient from forth to fifth tank and side outlet coefficient for fifth tank respectively, can be ignored. Therefore, it is concluded that the optimum number of tank for hourly runoff simulation for Bedup Basin is four.

6.0 CONCLUSIONS

Results revealed that the best number of tank for rural catchment in humid region was found to be four for both daily and hourly runoff simulation. The average R and E^2 obtained are yielding to 0.6833 and 0.6620 respectively obtained from 4-Tank-D, with the configuration of X1 = 10, X2 = 20, C1 = 0.001, C2 = 0.002, C3 = 0.42, C4 = 0.055, C5 = 0.6, C6 = 0.055, C7 = 0.83 and C8 = 0.000001. For hourly runoff simulation, the best average R and E^2 obtained are 0.8985 and 0.8214 respectively through 4-Tank-H model, with the configuration of C1 = 0.01, C2 = 0.002, C3 = 0.1, C4 = 0.01, C5 = 0.08, C6 = 0.05, C7 = 0.03, C8 = 0.05, X1 = 10 and X2 = 40.

The sensitivity analysis for daily runoff simulation also indicated that both infiltration coefficient from forth to fifth tank (C9) and side outlet coefficient for fifth tank (C10), have very little impact to simulation results. Thus, these two parameters can be neglected and ignored. This clearly confirmed that the fifth tank is not necessary and the best number of tank for rural catchment in humid region is four. ■

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