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T. Harianto
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Future Challenges in Civil Engineering Infrastructure Technology

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Lawalenna S.

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PREFACE

It is widely believed that the effect of climate change have increased the awarness of people on the severe impact of water and air pollution, the rise of temperature, and the limitation of energy deposites. Besides that, global warming and climate change have played significant role in the change of infrastructure technology. Consequently, the development of infrastructure technology will be evaluated in order to create ecology-environmental friendly and optimized energy.

Sharing knowledge of infrastructure and civil engineering technology which well agree with environmental preservation are valuable to be implemented in the *1st International Conference on Civil Engineering and Infrastructure : "Future Challenges in Civil Engineering Infrastructure Technology"*. The conference is organized by Badan Musyawarah Perguruan Tinggi Teknik Sipil Indonesia (BPMTTSI).

This conference is a media for civil engineers, infrastructure practitioners, academicians, environmentalists and research, to discuss, explore and share recent development and research of infrastructure and civil engineering technology. In future, this conferece will contribute in improving human resources.

Sincerely,

Dr. Tri Harianto
Chairman

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SIGNIFICANCE OF CONCEPTUAL RAINFALL – RUNOFF MODEL OVER SYNTHETIC UNIT HYDROGRAPH METHOD IN SIMULATING HIGH FLOW; CASE STUDY IN JIANGWAN CATCHMENT, CHINA

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ABSTRACT: This study evaluates the performance of both synthetic unit hydrograph (SUH-SCS method) and conceptual rainfall – runoff simulation (CRRS-HBV96 model) in estimating annual highest flow, using Jiangwan catchment as the study location with hydrological data from 1957 – 1969. The result explicitly shows the significance of CRRS over SUH method, as well as expresses the importance of qualified hydrological data series. Although SUH method requires simpler data demand, CRRS is principally found to be more accountable in delivering flow simulation. In HBV96 model simulation, hydrological characteristic annual changes are found through parameters alteration that goes in line with the actual catchment physical condition. The high flow simulation delivers average and standard deviation of the relative error respectively at 0.2123 & 0.2048. By applying the same concept using SCS-SUH method, optimum Curve Number (CN) parameter value increases from 50 to 52, delivering average and standard deviation relative error at 0.5514 & 0.3864 respectively. It is clear to see that CRRS produces better result compared to SUH method, due to its consideration to more variable expressed by numerous parameter. Further, it leads to evidence and expectation that developing countries should pay more attention and priority to their hydrometric system.

Key words: HBV96 model, SCS method, Jiangwan catchment, annual highest flow

1. Introduction

1.1. *General Background*

The development of hydrological analysis to estimate peak flow has been rapidly increased in recent years, starting from rational method, synthetic unit hydrograph (SUH) and conceptual rainfall – runoff simulation (CRRS) method. Each method is found to have its own assumption, suitability, strength and weaknesses. While rational method is often used to estimate peak flood in small-scale catchment from short duration precipitation (residential area, warehouse & industrial site development, etc), SUH & CRRS method are being used in larger scale catchment to produce deterministic or even continuous flow output. Initially, the usage was usually separated by using SUH in medium scale catchment and CRRS in large scale catchment. However, considering the data availability in developing countries, especially the hydrological and spatial data that holds crucial role in the analysis phase, SUH method is mostly preferable to be utilized to estimate peak flow even in large scale catchment due to its simpler data demand. Nevertheless, CRRS method assumptions are principally representing the analyzed basin in more detail characteristics and parameters; it includes the basin physical characteristics directly into its calculation, such as soil moisture, portion of impervious surface area, sub-surface flow proportion, evapotranspiration and so on. Although numerous CRRS are developed in different regions considering various hydrological characteristics in every area, satisfying results using different CRRS model are still found (Gan, et al., 1995; Rusli, et al., 2014, etc). On the other hand, each SUH methods have their own parameter that does not directly represents the basin physical condition, such as C_c and C_v parameter of Snyder method, CN parameter for SCS method, α for Nakayasu method, storage coefficient for Clark method, K for Gamma-1 method, etc. Besides, those SUH methods are developed in specific location; Snyder method in USA, SCS method in USA, Nakayasu method in Japan, Clark method in USA, Gamma-1 method in Indonesia, et cetera; and those methods are actually fits the best in the research locations sources, while for other locations, some adaptations and adjustments are highly required.

Moreover, differ from CRRS that could be adjusted based on physical condition, SUH method adjustment should involve more consideration since there is no specific representation for detail physical catchment characteristics.

This study basically is aimed to evaluate the significance of CRRS model over SUH method to estimate the annual highest flow, by taking Jiangwan catchment in Zhejiang Province, China as its sample study location. Secondary objectives of this study, besides the evaluation as the primary objectives, are to explicitly express the importance of hydrological and geospatial data availability to run the simulation using CRRS approach. As it has been mentioned above, the simulation by using CRRS requires more data demand, especially the spatial data to determine the value of the model parameter and the discharge measurement record to verify the model calibration and simulation. In such developing country like Indonesia where the hydrometrical and database system has not been the main focus of the government to develop, it is expected to be seen from this study result that simulation by using CRRS method deliver much better annual highest flow compared to SUH method; and its importance is significant related to flood management and mitigation policy.

1.2. *Brief Description of Study Location*

The study location for this research is taken place in Jiangwan catchment, located in Zhejiang Province, People's Republic of China as it is shown in Figure 1 below. It was designed to be a research catchment, where human interference to the natural hydrological circulation is strictly limited, since the year of 1957. Geographically, its outlet is located at $119^0 50'$ E and $30^0 35'$ N, making it a part of south China with seasonal characteristics of very short winter season. While the area of Jiangwan catchment is relatively small at 20.9 km^2, the hydrological data provision is very accountable with 10 rainfall stations and several discharge measurement station.

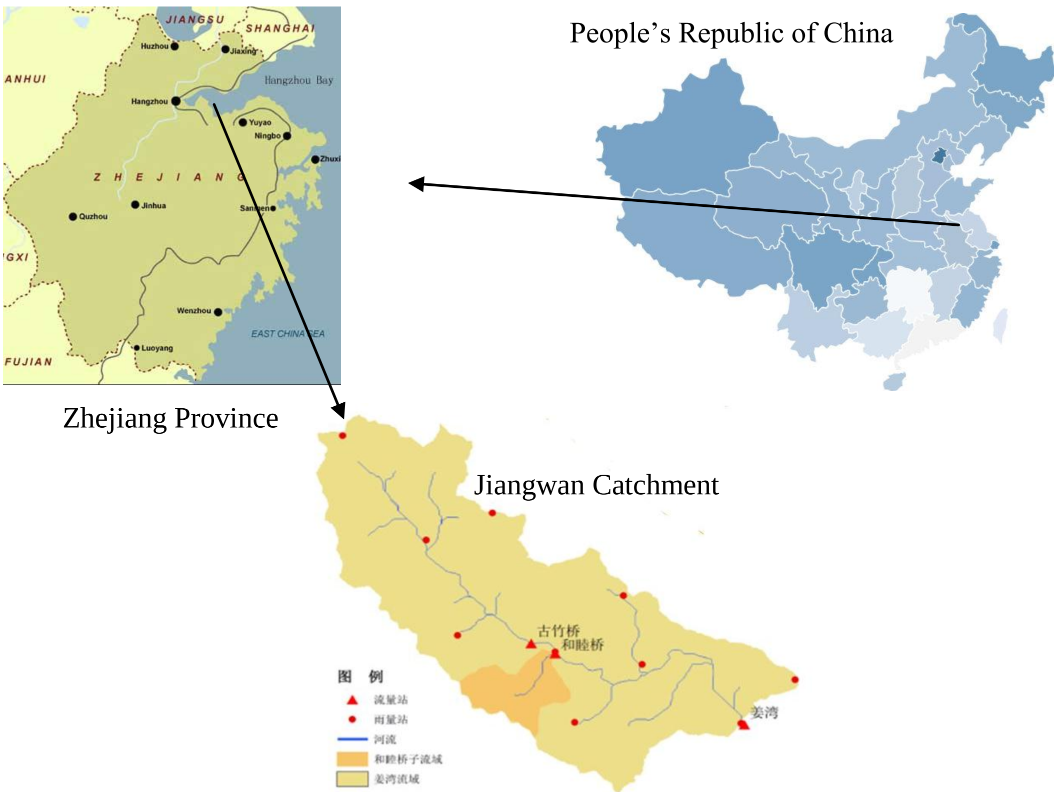

Figure 1. Jiangwan Catchment as Study Location

The hydro-meteorological data in Jiangwan catchment were recorded by Zhejiang Provincial Hydrology Bureau and tested according to the National Standard of People's Republic of China for Water Resources (2000). The distinguished feature of Jiangwan catchment is its uniform spatial distribution (90% of its terrain surface is covered by bamboo forest) and its undisturbed natural condition. Besides, its sub-surface feature is found to have lots of gaps and fissures, as it was previously studied by Le, et al. (2012). Presumption of altering parameter is then deducted, since unique geological feature has great significance in hydrology model parameter determination (Zhao, et al. 1980; Troch, et al. 2002).

Compilation of annual maximum daily rainfall and daily flow from 1957 to 1969 is compiled in following Figure 2 below, with the rainfall height is the result of regional rainfall analysis from 10 available rainfall stations.

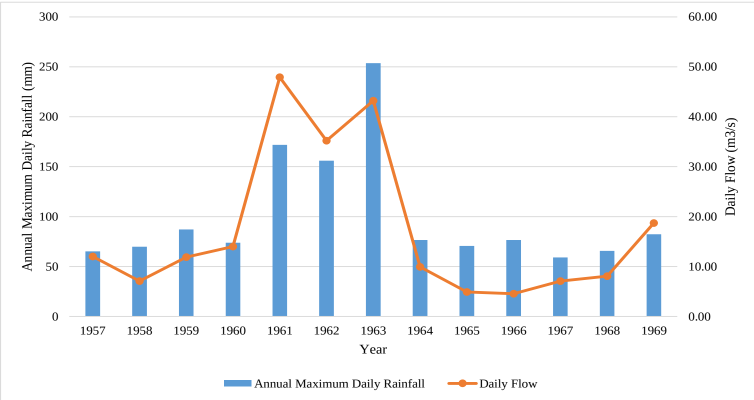

Figure 2. Annual Maximum Daily Rainfall & Daily Flow in Jiangwan Catchment

2. Research Methodology

Two methods are taken in this study as the representative of CRRS and SUH; HBV96 model represents CRRS considering its world-wide usage (Singh, 1995), and SCS model is chosen to represent SUH method considering its single parameter which ease the calibration process. By using the maximum daily precipitation and daily flow measurement record from 1957 to 1969, both model simulation is compared and evaluated. Detail steps of each model are explained below.

2.1. *Synthetic Unit Hydrograph – Soil Conservation Service (SCS) Method*

2.1.1. *Basic Concepts of SCS Method*

Soil Conservation Service Method, as known as SCS, is a method that widely used to process the loss of precipitation and the transform of rainfall data and catchment characteristic to a unit hydrograph. In both processes, the analysis refers and depends highly to curve number (CN) parameter, which is influenced by the soil type, land use and hydrologic condition, in range 1 to 100. Greater value of CN means more surface runoff occurred from the rainfall, while smaller value of CN means less surface runoff occurred from the rainfall. For an ungauged catchment, CN value can be estimated based on a reference defined by federal agencies (Ponce, 1989) as given in Table 1 below. Although it is stated that the curve number method is limited to maximum catchments of areas of 16 km^2 (Ponce, 1989), considering the spatial uniformity of Jiangwan catchment, this method is considered to be feasible to be used in this study.

Under a rainfall occurrence, SCS method calculates the total loss during a rainfall as infiltration. The incremental infiltration, which commonly starts with value of 0.2 of potential retention of the catchment, is then continued as a constant rate depending on the CN value. On the other hand, to transform the rainfall and catchment characteristic into a unit hydrograph, the SCS synthetic unit hydrograph method expresses the hydrograph in form of a dimensionless unit hydrograph. In SCS method, the lag time of the catchment is expressed by the following formula:

$$t_l = \frac{L^{0.8}(2540 - 22.86CN)^{0.7}}{14104CN^{0.7}Y^{0.5}} \quad (1)$$

where t_l is catchment lag (hours), L is hydraulic length (meters), CN is runoff curve number and Y is average catchment land slope (meter per meter). With the assumption that the rain falls uniformly, the time to peak (t_p) and peak flow of the SCS UH is calculated by:

$$t_p = \frac{10}{9} t_l \quad (2)$$

$$Q_p = \frac{2.08A}{t_p} \quad (3)$$

where t_p is time to peak (hours), Q_p is peak flow (cubic meter second) and A is catchment area (meter square). After the calculation, the unit hydrograph is then configured by certain proportion to t_p and Q_p, which is shown in Table 2 below.

Table 1. Curve Number (CN) Value as the Main Parameter of SCS Method

Land Use Description		Hydrologic Soil Group			
		A	B	C	D
Cultivated Land: without conservation treatment		72	81	88	91
Cultivated Land: with conservation treatment		62	71	78	81
Pasture or range land: poor condition		68	79	86	89
Pasture or range land: good condition		39	61	74	80
Meadow: good condition		30	58	71	78
Wood or forest land: thin stand, poor cover, no mulch		45	66	77	83
Wood or forest land: good cover		25	55	70	77
Open spaces, lawns, parks, golf courses, cemeteries, etc					
Good condition: grass cover on 75% or more of the area		39	61	74	80
Fair condition: grass cover on 50% to 75% of the area		49	69	79	84
Commercial business area (85% impervious)		89	92	94	95
Industrial districts (72% impervious)		81	88	91	93
Residential[3]:					
Average lot size	Average % impervious				
1/8 acre or less	65	77	85	90	92
¼ acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
½ acre	25	54	70	80	85
1 acre	20	51	68	79	84
Paved parking lots, roofs, driveways, etc		98	98	98	98
Street and roads:					
Paved with curbs and storm sewers		98	98	98	98
Gravel		76	85	89	91
Dirt		72	82	87	89

Table 2. SCS Dimensionless UH Ordinates

t/t_p	Q/Q_p	t/t_p	Q/Q_p	t/t_p	Q/Q_p	t/t_p	Q/Q_p	t/t_p	Q/Q_p
0.00	0.00	0.70	0.820	1.40	0.780	2.20	0.207	3.60	0.021
0.10	0.030	0.80	0.930	1.50	0.680	2.40	0.147	3.80	0.015
0.20	0.100	0.90	0.990	1.60	0.560	2.60	0.107	4.00	0.011
0.30	0.190	1.00	1.000	1.70	0.460	2.80	0.077	4.50	0.005
0.40	0.310	1.10	0.990	1.80	0.390	3.00	0.055	5.00	0.000
0.50	0.470	1.20	0.930	1.90	0.330	3.20	0.040		
0.60	0.660	1.30	0.860	2.00	0.280	3.40	0.029		

2.1.2. *SCS Application Methodology*

In this study, initially the CN parameter is calibrated by conducting trial and error process to link the rainfall height and daily flow under certain return period. After doing frequency analysis on the data set, the 2, 5 and 10 return period of rainfall and flow is obtained; then calibrated by using the help of HEC-HMS software to implement the SCS method. The relative deviation of each return period is then averaged, and the best CN is taken as the representative CN (CN_1). By using CN_1, hydrological analysis to estimate peak flow is then conducted by applying various annual maximum daily precipitation into the model. The output is the annual highest flow, obtained from the hydrograph peak flow, and the result is further compared and evaluated by plotting it into a graph along with the CRRS output and the actual flow data measurement record.

2.2. *Conceptual Model – Hydrologiska Byrans Vattenbalansavedlning (HBV) 96*

2.2.1. *Basic Concepts of HBV96 Method*

As HBV96 model resolution is limited to daily time-step, the required data to run simulation in non-snowy area is also limited to daily precipitation and daily flow data. Climatological data to calculate potential evapotranspiration can be necessary; but under circumstance where actual evapotranspiration measurement is available, analysis for potential evapotranspiration is not further a must.

Without any consideration of snow routine process, HBV96 model structure consists of three soil boxes as shown in Figure 3 below. Each component, which is determined by the parameter value, connects every water flow among those boxes; starting from precipitation in soil box to runoff estimation as the simulation output. The primary parameters in HBV96 model structure are expected to represent the actual catchment response; they are FC (maximum soil moisture storage capacity), LP (evapotranspiration limitation), CFLUX (velocity of water flowing up through the soil due to capillarity force), PERC (velocity of water flowing down due to natural percolation process), k_f (coefficient for sub-surface discharge), k_4 (coefficient for groundwater discharge), α (power coefficient for sub-surface discharge), and β (power coefficient for recharge and percolation). There are actually other parameters such as MAXBAS, however, it can be unobserved since it is an integral parameter (Zhang and Lindstrom, 1997). The formula to calculate each component are mentioned below.

$$EA = \frac{SM}{LP} EP \qquad (4)$$

$$R = P \frac{SM_0}{FC}^{\beta} \qquad (5)$$

$$CF = CFLUX \frac{FC - SM}{FC} \qquad (6)$$

$$SM = SM_0 + P + EA + CF \qquad (7)$$

$$Percolation = PERC\frac{SM^{\beta}}{FC} \quad (8)$$

$$Q_{uz} = K_f h_{uz}^{\alpha+1} \quad (9)$$

$$h_{uz} = h_{uz_0} + R - CF - Percolation - Q_{uz} \quad (10)$$

$$Q_{lz} = K_4 h_{lz} \quad (11)$$

$$h_{lz} = h_{lz_0} + Percolation - Q_{lz} \quad (12)$$

$$Q_{total} = Q_{uz} + Q_{lz} \quad (13)$$

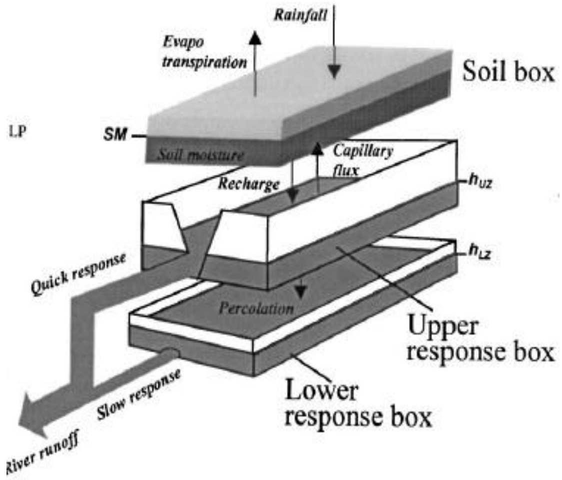

Figure 3. HBV96 Model Structure

2.2.2. *HBV Application Methodology*

To involve general water balance analysis that includes calibration and verification steps, the temporal variation is divided into three periods in this study; 1957 to 1960, 1961 to 1963 and 1964 to 1969. However, it is given the effort so the parameter alteration goes along with the actual physical condition of the catchment in suitable manner, and the changing has to be scientifically acceptable. Change in surface parameter is avoided since the terrain cover of Jiangwan catchment is mostly unchanging; however, change in sub-surface layer should go in line with the Jiangwan geological feature. After calibrating the model parameter, then the result is further compared and evaluated by plotting it into a graph along with the CRRS output and the actual flow data measurement record.

3. Results & Discussion

By doing the frequency analysis beforehand, it is obtained that the rainfall height under 2, 5 and 10 return period in Jiangwan catchment respectively are 81.4 mm, 122.7 mm and 163.0 mm;, while the flow under same return period are 11.90 m^3/s, 24.00 m^3/s and 36.1 m^3/s. The calibrated CN (CN_1 = 50) goes in line with the table value (CN wood or forest land with good cover is approximately at 55 value), and it delivers averagely 27.66% relative deviation, fits the most with flow under 5 years return period (2.98% relative deviation). Nevertheless, the calibration of CN parameter shows the non-linearity characteristics of CN value; different rainfall height tends to give different value of CN as well. However, in this study, as generally done by SUH-SCS method, one representative parameter of CN_1 is taken to be constantly applied in Jiangwan catchment.

On the other hand, by using HBV96 model, several parameter alterations are found, as hypothetically mentioned before, considering the sub-surface condition of Jiangwan catchment. However, the alterations are still acceptable, since the changing parameter are mostly found in sub-surface area (k_f, α, PERC and β) and the actual catchment physical condition provides good agreement with it. Other parameter such as FC, LP, CFLUX and k_4 are found to be constant.

Furthermore related to annual high flow estimation, the results of both approaches delivers different output accuracy. Averagely, the relative deviation obtained from respectively HBV96 and SCS method are 21.23% and 55.14%, and the standard deviation of the same evaluation function are 20.48% and 38.64%. Figure 4 below shows the actual highest annual flow data record and the deliverance from HBV96 and SCS estimation.

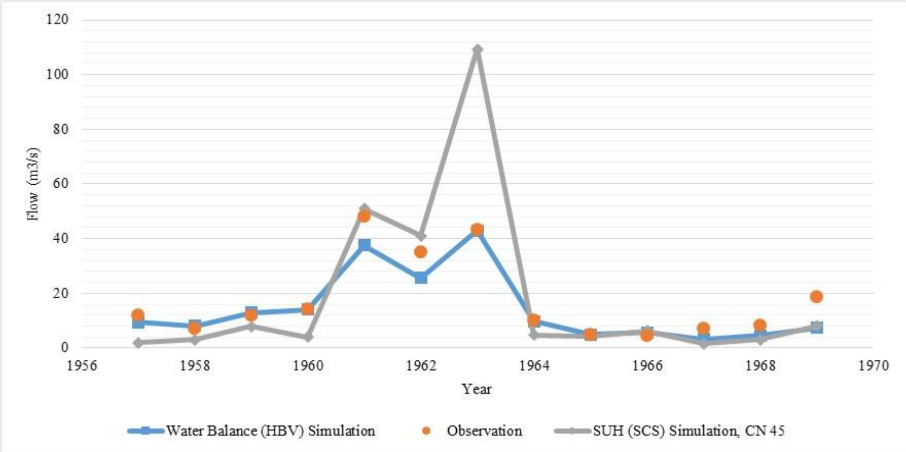

Figure 4. Flow Measurement Record versus Result Analysis

It can be seen from the figure that HBV96 estimation (blue line) has higher accuracy in approaching the observation data (orange dot) than the SCS method estimation (grey line). Quantitatively, the relative deviation of each year simulation is shown in Table 3 below.

Table 3. Relative Deviation of Each HBV96 and SCS Annual Highest Flow Estimation

Year	Flow (m^3/s)			Deviation (%)	
	Observation	HBV96	SCS	HBV96	SCS
1957	12.00	9.47	1.90	21.06	84.17
1958	7.08	8.07	3.00	13.96	57.63
1959	11.90	12.86	8.00	8.07	32.77
1960	14.00	14.00	4.00	0.02	71.43
1961	47.90	37.63	50.90	21.44	6.26
1962	35.20	25.63	41.10	27.20	16.76
1963	43.20	43.02	109.20	0.42	152.78
1964	9.92	9.69	4.70	2.36	52.62
1965	4.91	4.92	4.40	0.12	10.39
1966	4.55	5.70	6.20	25.21	36.26
1967	7.07	3.29	1.60	53.39	77.37
1968	8.08	4.53	3.10	43.93	61.63
1969	18.70	7.44	8.10	60.22	56.68

Very small deviation is found on some of HBV96 simulation, such as in year 1960 (0.02%) and 1963 (0.42%). Such result cannot be obtained by using SUH-SCS method, where the closest simulation with the observation delivers 6.26% deviation. Especially for the highest rainfall occurrence of 253.67 mm in 1963, the deviation delivered by the SCS method is very high (152.78%). It is analyzed to happen due to the deterministic concept of SUH approach; while in CRRS concept, the previous daily soil moisture condition is taken into account, and each catchment physical attributes are represented by one parameter. Besides, it is also indicates the significance of continuous model over event-based simulation. Moreover, the only parameter of SCS method, CN, represents the surface condition, not the sub-surface condition, that gives bigger influence in Jiangwan catchment simulation. Should the data is available, the result of this study highly suggests the usage of CRRS method over SUH method.

4. Conclusions

Some conclusions can be derived from this study are as follow:

1. In terms of estimating annual high flow, SUH method is still preferable to be used in developing countries due to its simpler data demand than CRRS method. Nevertheless, conceptually CRRS method offers more suitable simulation in estimating flow. In this study, the significance of CRRS method over SUH is studied; with HBV96 model and SCS method represents each approaches.
2. Jiangwan catchment, which is used as the study location, is a research catchment in Zhejiang Province, China. On the terrain surface, the cover of Jiangwan catchment is mostly undisturbed by any human or land development. However, in the sub-surface layer, geologically many faults and gaps are found. Further it caused the inconstant value of sub-surface parameter of the model.
3. From the SCS method calibration, it is found that the most suitable CN parameter of Jiangwan catchment is 50. By using SCS method, the average and standard deviation of the relative deviation are respectively 55.14% and 38.64%.
4. In HBV96 model simulation, some parameter alter in certain temporal variability. However, the parameter alteration is accountable since the surface layer parameter are found constant, while the sub-surface parameter are not. The mentioned fact shows the suitability of the model to the actual catchment physical condition. By using HBV96 model, the average and standard deviation of the relative deviation are respectively 21.23% and 20.48%.
5. The result of this study significantly shows better performance of CRRS concept over SUH approach. As it is known that more precise, continuous and reliable data is needed to perform CRRS analysis, the awareness of developing countries about the importance of hydrological-related data is hoped to be increased.

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