Evaluation of Runoff in the Upper-Chi and Lumsapung Basins using Hydrologic Model and Mathematical SWAT Model

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Abstract. *Runoff evaluation can be done in several ways ranging from traditional basic hydrological methods to mathematical models with computer programs. Each method has different conditions and limitations, such as hydrological methods which use simple calculation process and only a few parameters, but may give less accuracy results than the mathematical model that requires more input data and more complex preparing parameters as well as more parameters for calibration steps. Therefore, this study aims to apply basic hydrological methods for evaluating total-runoff to provide acceptable results as close as the target mathematical model. The study areas were in Upper-Chi River basin and Lamsapung basin, Thailand. The proportions or relationships in the new forms of CN' and C' from the basic SCS-CN and Rational methods respectively were created. The new forms could be used as representative variables for evaluating run-off and giving accepted results close to the results of mathematical model (SWAT model). The results showed that all 3 methods could be used to evaluate the total runoff with good results. Furthermore, the new variables of CN' and C' which represented variables for evaluating the total-runoff with SCS-CN and Rational methods provided acceptable results in the forms of monthly values.*

1. Introduction

Runoff is necessary information for water resource management; especially, in flood and draught control affecting from land use and climate changes [1-2]. There are a number of different definitions of runoff that have been used either explicitly or implicitly in hydrological analyses over the years. If the amount of water falling on the ground is greater than the infiltration rate of the surface, the runoff or overland flow will occur. Runoff specifically refers to the water leaving an area of drainage and flowing across the land surface to points of lower elevation. It is not

the water flowing beneath the surface of the ground [3]. This type of water flow is commonly called through flow. Runoff involves the following events: 1) rainfall intensity exceeds the soil's infiltration rate 2) a thin water layer forms that begins to move because of the influence of slope and gravity 3) flowing water accumulates in depressions 4) depressions overflow and form small rills 5) rills merge to form larger streams and rivers 6) streams and rivers then flow into lakes or oceans [4-5]. Total runoff or the amount of water measured in the river consists of 3 main parts, namely surface run-off, sub-surface run-off and groundwater base flow as described in Fig. 1 [6].
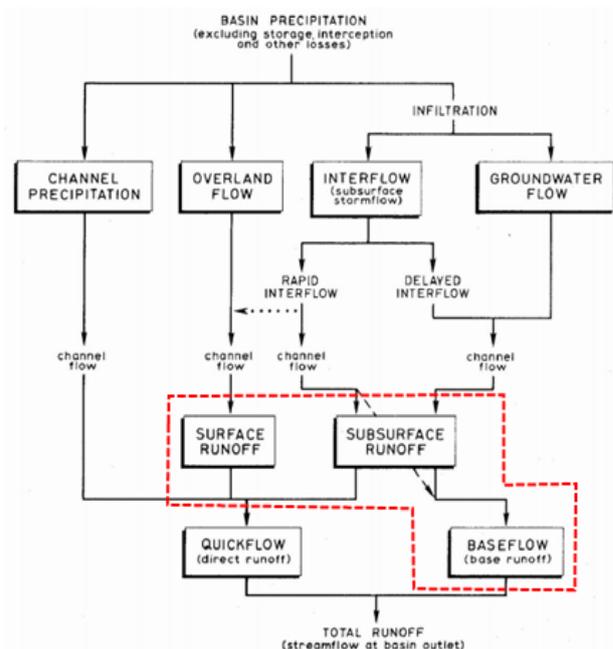

Fig. 1: Total runoff process [6]

Soil and Water Assessment Tool (SWAT) is a river basin scale model developed to quantify the impact of land management practices in large, complex watersheds. SWAT is a public domain software enabled model actively supported by the USDA Agricultural Research Service at the Black land Research & Extension Center in Temple,

Texas, USA [7]. It is a hydrology model with the following components: weather, surface runoff, return flow, percolation, evapotranspiration, transmission losses, pond and reservoir storage, crop growth and irrigation, groundwater flow, reach routing, nutrient and pesticide loading, and water transfer. SWAT can be considered a watershed hydrological transport model [8]. SWAT is a rainfall-runoff model that has been widely accepted [9].

The SCS curve number method (SCS-CN) is a simple widely used and efficient method for determining the approximant amount of runoff from a rainfall even in a particular area. Although the method is designed for a single storm event, it can be scaled to find average annual runoff values. The stat requirements for this method are very low, rainfall amount and curve number. The curve number is based on the area's hydrologic soil group, land use, treatment and hydrologic condition [10]. The Rational equation is the simplest method to determine peak discharge from drainage basin runoff [11]. Both SCS-CN and Rational methods have their own only one important parameter such as CN and C respectively.

However, the amount of runoff apart from the surface run-off will have a relative proportion to surface run-off. Because they were all generated from the same rain event that caused the surface run-off as described in Fig. 2 [12]. If such proportions or relationships could be found and included to become new variables of CN' and C', then those could be used as agents to evaluate total run-off.

Therefore, this study thus applied the basic hydrological method of SCS-CN and rational methods for evaluating total-runoff to provide acceptable results as close to the mathematical model of SWAT model. The proportions in forms of CN' and C' from the basic SCS-CN and rational methods respectively were found out. The study area covers the Lamsapung basin and the upper-Chi-River basin, which are a sub-basin of the Chi River Basin in Chaiyaphum province as shown in Fig. 3.
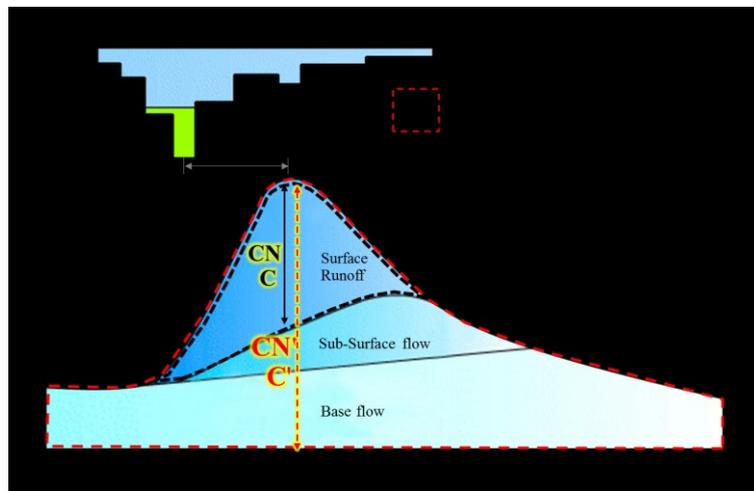

Fig. 2: Runoff relationship of CN, C with CN', C' variables (Modified from [12])
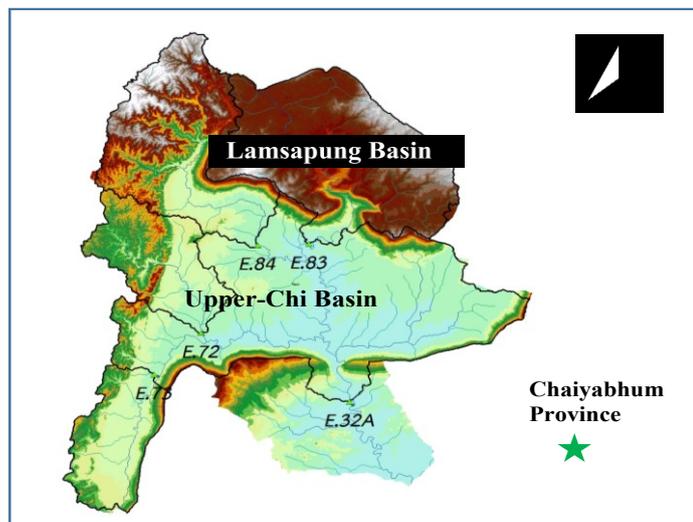

Fig. 3: Study area of Upper-Chi and Lamsapung basins

2.   Methodologies

For evaluating runoff from rainfall in this study, the data and the results are considered in monthly form. Important input data consisted of measured rainfall data and measured discharge data from the measurement stations. The data ranges used were 2007-2016 with E.32A stations as a point for calibration (2007-2013) and verifying (2014-2016). The watershed area at the exit point of the measurement station E.32A is 2,733.8 km^2. The performance indicators used were R^2, E, PBIAS, with accepted values are 0.5-1, close to 1, and close to 0 respectively. Finally summarize the results of each method. The steps of procedure were shown in Fig. 4.

2.1 SWAT

The SWAT model was implemented through the ARCSWAT program as an add-in module in the ArcGIS program. The necessary input data required were GIS maps consisted of: 1) Digital Elevation Map (DEM) 2) Land-use Map 3) Soil Type Map 4) Rivers Map 5) Locations map of rainfall and weather stations.

The main important procedure is to overlay the 3 GIS maps of DEM, Land-use and Soil-type (shown in Fig. 5) and process together as a hydrological Response Unit map (HRUs). Those were used to analyze the runoff from the amount of rainfall.
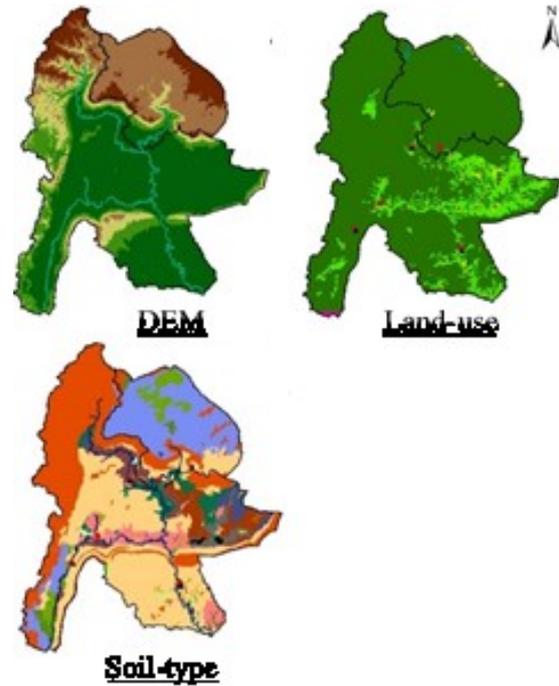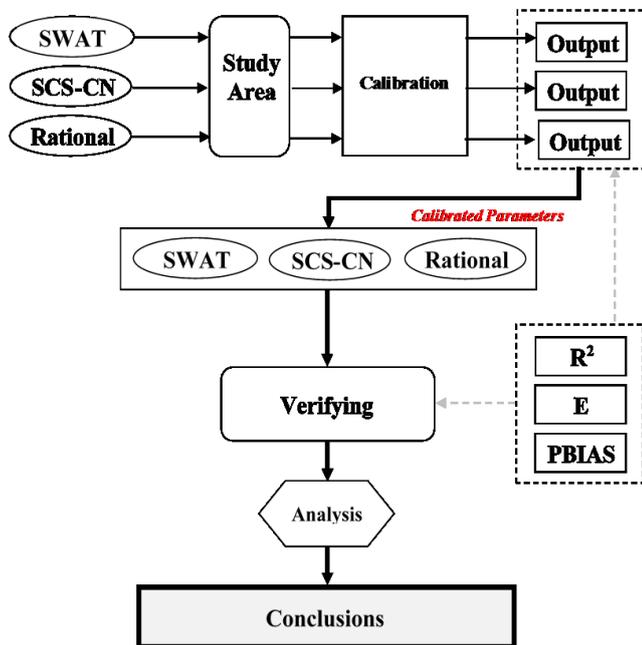

Fig. 5: GIS Maps for HRUs analysis

2.2 SCS-CN

The SCS-CN method used the relationship equation the following:

$$Q_{surf} = \frac{(R_{day} - I_a)^2}{(R_{day} - I_a + S)} \qquad (1)$$

and

$$S = (\frac{25400}{CN}) - 254 \qquad (2)$$

; where

Q$_{surf}$ = Depth of surface runoff (mm)

R$_{day}$ = Daily rainfall (mm)

I$_a$ = Depth of intercept (mm)

S = Retention Parameter (mm)

CN = Curve Number (0-100)

Which the S value is varying depending on soil type and use, surface slope and the amount of moisture in the soil at various times. Which is included in a single variable called curve number (CN). The CN showed the soil's permeability. CN will have a value between 0 and 100 as shown in Fig. 6 [13], while the I$_a$ value approximately equals to 0.2S [14].

This study used the equations (1) and (2) to apply for monthly total runoff value as follows:

Fig. 4: Work flow of study methodology

$$Q_{total} = \frac{(R_m - I_a)^2}{(R_m - I_a + S)} \times Area \qquad (3)$$

and

$$S = \left(\frac{25400}{CN'}\right) - 254 \qquad (4)$$

; where

Q_{total} = Total runoff (million cubic meters)

R_m = Monthly rainfall (mm)

I_a = Depth of intercept (mm)

S   = Retention Parameter (mm)

Area   = Watershed area (sq.km.)

CN' = Modified Curve Number (0-100)

Which the progress used to determine CN' is trial and errors method. By applying the method to each month of individual year and figuring the equation for result of Q_{total} value to be close to the measurement value then bringing the CN' value that has been averaged to be as a CN' representative for individual month for evaluating the total-runoff from rainfall amount.
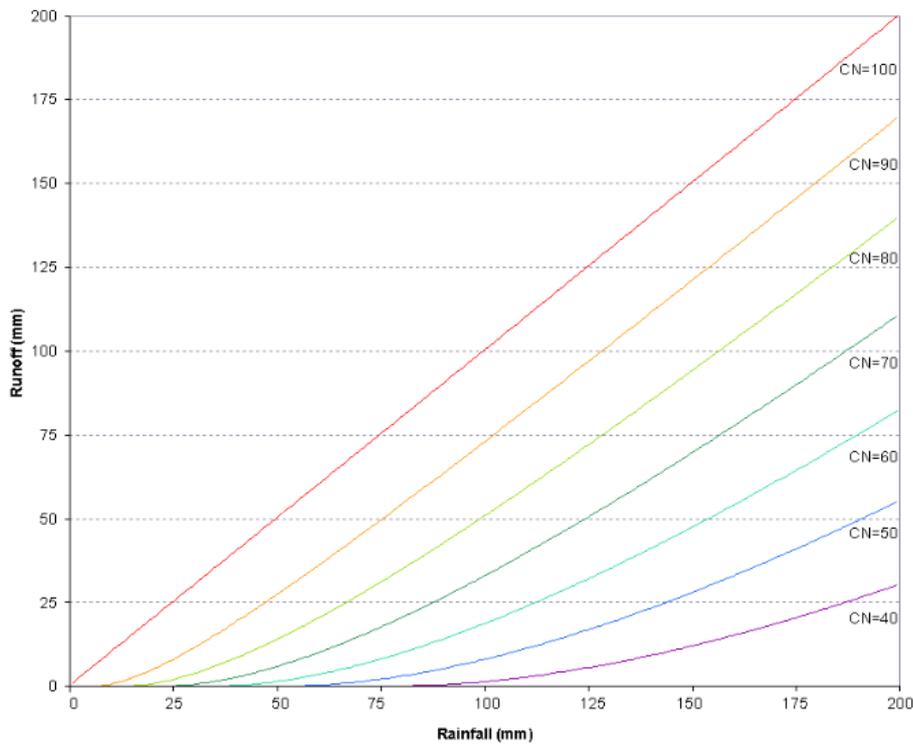

Fig. 6: Relationship between surface runoff and daily rainfall and CN values [13]

2.3 Rational Method

The rational method equation is presented as the following:

$$Q = 0.278 \ CIA \qquad (5)$$

; where

Q = Maximum discharge (cms.)

C = Runoff coefficient

I = Rain intensity (mm / hr)

A = Watershed area (sq.km.)

The C value was determined approximately with conditions and boundary values according to the suggested values in the Table 1.

Land-use / Land cover	C
Agricultural area	0.20-0.30
Desolate area	0.10-0.30
Residence area low-density	0.40-0.45
Residence area medium-density	0.50-0.55
Residence area high-density	0.55-0.60

Table 1: Ranged values of coefficient C for Rational method

In this study, rain intensity (I) was applied to the average monthly rainfall intensity calculated from:

$$\frac{\text{Monthly rainfall (mm)}}{\text{(Number of days in a month x 24)}} \qquad (6)$$

In terms of the C value, it was determined to vary according to the number of rainy days and the amount of rainfall. That is, if there is continuous rain then water storage capacity in soil will be less remaining. Rainfall will become more as surface runoff. That caused the different C values of each month for same area. Which will call this monthly C as C'.

3.   Results and Discussion

The results of runoff evaluated by 3 methods compared with measured values over time period of both calibration (Jan 2007 – Dec 2012) and verifying (Jan 2013 – Dec 2016) have shown in Fig. 7 with R^2 indicated. Also, Table 2 shows the resultant values of statistical indicators by the 3 methods. They indicated that all methods are clearly applicable with acceptable results. The detail discussion is described as following:

The overall picture of the whole basin, at the outlet of station E.32A, the values of R^2 for entire 3 methods were relatively high over time period of both calibration and verifying (0.78-0.86).

The model efficiency (E) of every method was greater than 0.8 (0.82-0.87) in calibration time period. Meanwhile, in the period of verifying the Rational Method gave the highest efficiency of 0.79. But the other two gave less efficiency index of 0.51-0.59 but acceptable.

The last indicator of the data differences (PBIAS) showed that in calibration period SWAT model gave the least difference of 3.18 mcm. yearly but giving the highest difference of 72.96 mcm. in the verifying time period. The other two of SCS-CN and Rational methods gave the calibrating data differences of 16.99 and 19.35 mcm. yearly, respectively. In the time of verifying SCS-CN turned the higher difference of -27.71 mcm. yearly while the Rational gave the best result of 1.63 mcm. yearly.

The coefficients used for evaluating total-runoff by the SCS-CN method (CN'), Rational method (C') are shown in the form of monthly representative value as displayed in the Table 3.

The CN' of SCS-CN method indicated that the coefficient values in the rainy season (May-Oct) were slightly different within ranged values of 46-52. Except the last two months: the September and the October, they started higher to 61 and 86, respectively. Because the September is the month with the highest amount of rainfall and the rainfall inception of soil and land-use became filled. That made rainfall turned to be more runoff. This also happened continually to the October, which is the season transit month to dry season. Rainfall became lowering as well as the surface runoff but sub-surface and base flow started discharging more influenced in total runoff volume.

The C' of Rational method indicated the same direction as well as the CN'. That was in the rainy season the C' value was not significant changed within ranged values of 0.31-0.39. Then it was significant rising up in the September and the October.

Comparing the C' to the normal C values in Table 1, rainy season concerning, it is seen that the C' (0.31-0.39) was 40% higher than normal C of the study area (0.2-0.3).

Index	SWAT		SCS-CN		Rational	
	Calibration	Verifying	Calibration	Verifying	Calibration	Verifying
R^2	0.81	0.79	0.81	0.79	0.86	0.78
E	0.82	0.51	0.83	0.59	0.87	0.79
PBIAS	3.18	-72.96	16.99	-27.71	19.35	1.63

Table 2:   Statistic result of 3 methods

Parameters	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
CN'	72	75	69	53	47	52	51	46	61	86	66	73
C'	0.12	0.12	0.17	0.22	0.32	0.31	0.35	0.39	0.89	0.69	0.52	0.48

Table 3: Monthly value of new coefficients of CN' and C'

(a) SWAT Model

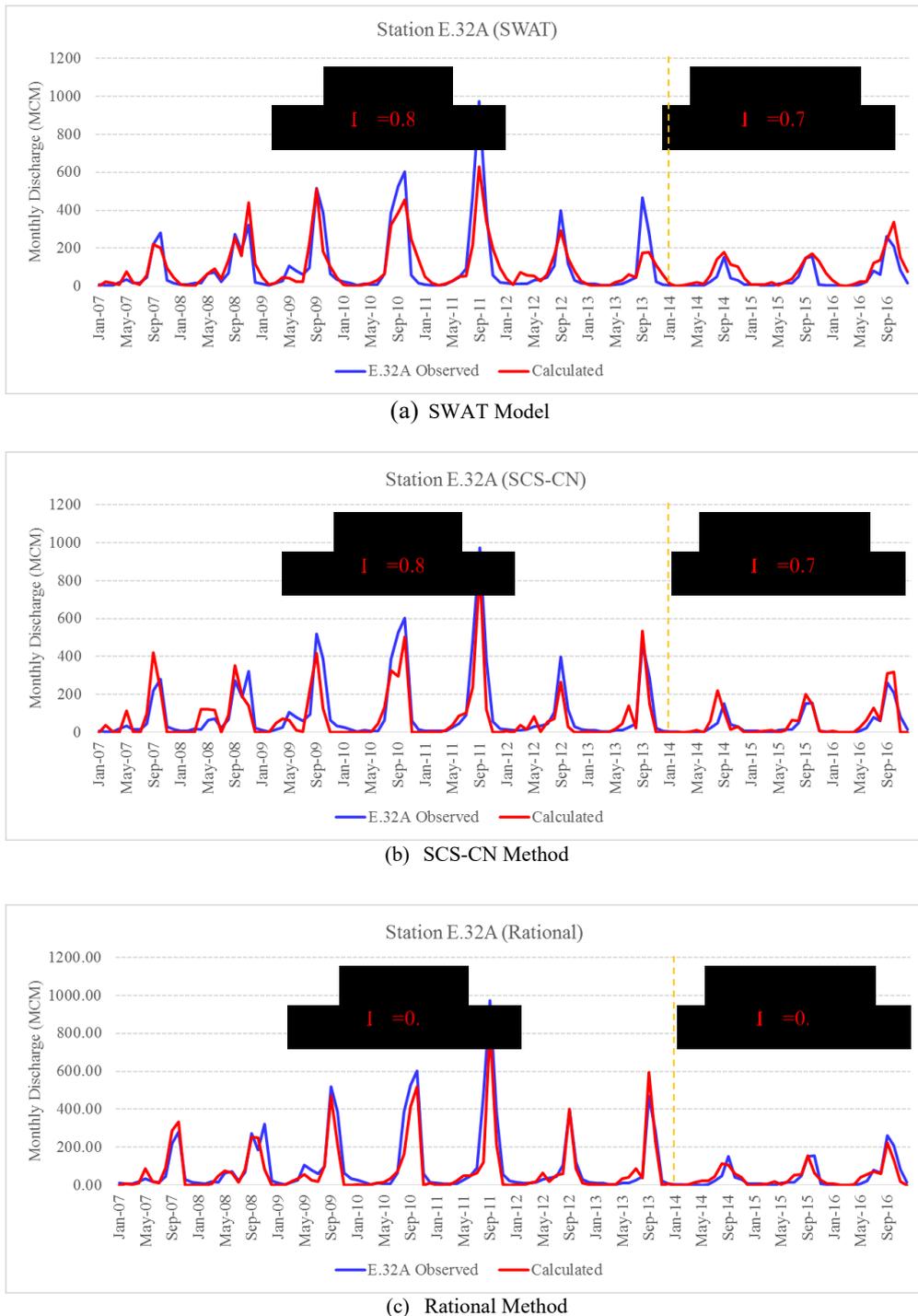(b) SCS-CN Method

(c) Rational Method

Fig. 7: Results graphs of SWAT, SCS-CN and Rational methods

4.   Conclusion

In this study, it can be concluded that basic methods of hydrology, both SCS-CN and Rational methods, could be applied to evaluate total-runoff on the study area with acceptable results by using the new coefficients of CN' and C', respectively. The result showed also better approach to the SWAT model. That could make total-runoff evaluating much easier with less complicated procedure by applying new modified CN' and C' to basic hydrological methods of SCS-CN and Rational, respectively. In addition, this could be useful for water management studying and planning. However, it is suggested to have further studies in daily time steps which would be necessary for applying in flood management as well.

5. Acknowledgement

6. References

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Biographies

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