Calibration of the Soil Conservation Services (SCS) Method in Peninsular Malaysia Using Sungai Tasoh Catchment, Negeri Perlis

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ABSTRACT
The Soil Conservation Services (SCS) Method has been developed and widely used in the United States to estimate catchment runoff. The used of this method in Malaysia needs readjustment to the variables of the SCS method. Therefore it is desirable to explore an approach and methodology to calibrate the SCS method using observed streamflow data in Peninsular Malaysia, This paper presents the findings of the calibration of the Soil Conservation Services Method using observed streamflow record of Sungai Tasoh Catchment in Negeri Perlis. The calibration of the SCS Method involves two variables, that are the local correction coefficient factor for curve numbers CN, and the correction coefficient factor for K value. After these correction coefficient factors are determined then the SCS Method will be used to estimate peak runoff from an ungauged catchment within the same region of the catchment used in the calibration. The SCS Method makes use of runoff curve numbers CN for selected soil groups, catchment land use and antecedent moisture condition to estimate the Peak runoff from an ungauged catchment.

1 Introduction

The SCS Method which was developed by the Soil Conservation Service (now known as the Natural Resources Conservation Service) is based on a dimensionless unit hydrograph, developed from a large number of unit hydrographs ranging in size and normally were obtained from observed hydrographs in the same geographical location of interest. Unit hydrographs were evaluated for a large number of actual watersheds and then made dimensionless by dividing all discharge ordinates by the peak discharge and all time ordinates by the time to peak. An average of these dimensionless unit hydrographs was computed. The hydrograph is represented as a simple triangle with rainfall duration D (hr), time of rise T_R (hr), time of fall B (hr), and peak flow Qp (cfs or cumecs). This hydrograph reflect the catchment characteristic of actual watershed in the United States. Therefore, for application in this region, it is desirable to calibrate the parameters of the SCS method to exhibit the condition in Malaysia.

The objective for the selection of the SCS Method is to have an alternate method to estimate the runoff from rural, and or mixed development catchments in Peninsular Malaysia. The SCS Method classified soils into four hydrologic soil groups (A, B, C, and D) according to their infiltration rate, which is obtained from bare soil after prolonged wetting. The runoff curve number is determined based on land use and hydrologic soil group. For a catchment with several soil types and land use, a composite curve number can be calculated based on the weighted percentage of the land use.

2 Methodology

Figure 1 shows the location of the Sungai Tasoh catchment, strearnflow and rainfall stations. There are two rainfall stations that are located within and near the catchment.

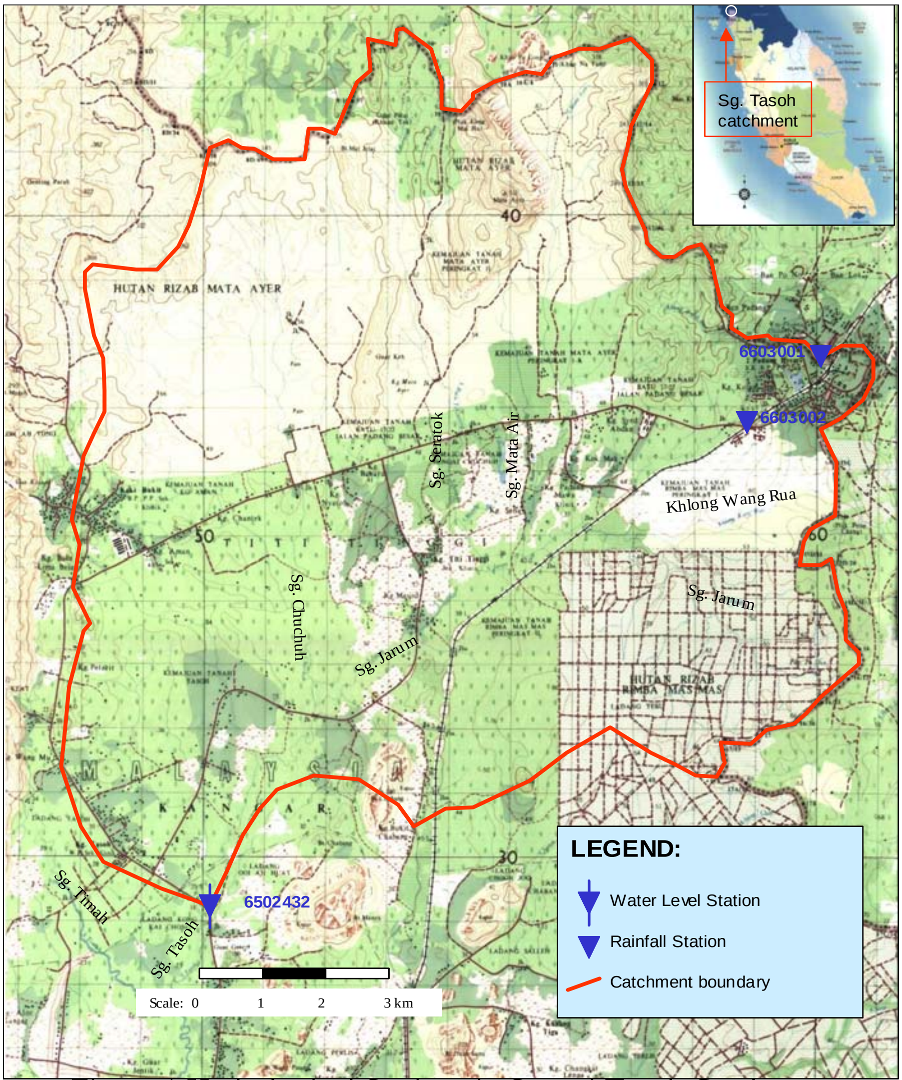

Figure 1 Hydrological Stations in Sungai Tasoh Catchment.

These stations are of automatic recording type. Table 1 shows the name and station number for these stations mentioned above. The Timah-Tasoh dam that is about 2.8 km downstream of the streamflow recorder was constructed in mid-1980s. The reservoir of the dam does not interfere with the readings of the automatic streamflow recorder.

Table 1 Rainfall and Streamflow Stations in Sungai Tasoh Catchment (Bahagian Pengairan dan Saliran, 1988).

Station No.	Station Name	Recording Type	Year of Record
6502432	Sg. Tasoh at Titi Konkerit Baru	Streamflow, Automatic	Automatic recorder started from 08/1978 to present.
6603001	Padang Besar	Rainfall, Automatic	Automatic recorder started from 09/1969 and **CLOSED** 11/1975. Prior to 1969, this is a manual station.
6603002	Padang Besar at Titi Keretapi	Rainfall, Automatic	Automatic recorder started from 11/1974 to present

To derive the observed unit hydrographs of Sg. Tasoh catchment, the rainfall station at Padang Besar at Titi Keretapi will be used in the analysis. Hourly rainfall and streamflow records will be used to analyze the unit hydrographs for the calibration of the correction coefficients, cfn and cf. Several good quality storms were selected for the analyses and from these, four storms were used to derive the unit hydrographs. The Perlis state is a relatively dry area of the Peninsular Malaysia with a mean annual rainfall of 1920 mm which is lower than most of the other regions of Peninsular Malaysia. The annual rainfall in the state varies from 2200 mm in the south to about 1700 mm in the northeast.

The criteria for selection of storms used in the analyses are as follows:

a) The storms should be selected with a simple hydrograph with relatively uniform spatial and temporal distributions

b) The catchment area should be within the limits of applicability unit hydrograph method that is not more than 500 square kilometers

c) The duration of rainfall excess should be approximately 25-30% of the time to peak tp.

The essential steps for developing a unit hydrograph from a single storm hydrograph are as follows:

a) Analyze and separate the base flow from the hydrograph;

b) Measure the total volume of Direct Runoff (DRO) under the hydrograph and convert this volume to Depth over the catchment;

c) Convert total rainfall to rainfall excess and evaluate duration D for the DRO hydrograph and the unit hydrograph;

d) Divide the ordinates of the DRO hydrograph by the volume in depth and plot the unit hydrograph.

From the SCS Method, the time to peak tp is given by the formula:

$$tp = \frac{(S+1)^{0.7}\ell^{0.8}}{1900\sqrt{y}} \qquad (1)$$

where:

$$S = \left(\frac{1000}{CN'}\right) - 10 \qquad (2)$$

$$CN' = cfn * CN \qquad (2a)$$

and

ℓ = length to divide, feet (m)
y = average catchment slope, %
CN' = adjusted Curve Number based on local catchment condition by observed master unit hydrograph

cfn = correction coefficient for curve number
CN = Curve Number, based on soil groups and land cover
S = Potential Maximum retention after runoff begins, inches (mm)

The time of rise T_R is given by

$$T_R = \frac{D}{2} + tp \qquad (3)$$

where:

D = Duration of the excess rainfall, hours obtained from rainfall data assume constant losses
T_R = Time of Rise, hours

The, Peak Unit Hydrograph Runoff is given by:

$$q_P = \frac{[K'AR]}{T_R} \qquad (4)$$

where:

R = Excess Rainfall (equals to I inch for Unit Hydrograph)
A = Catchment Area, square miles
K' = Peak attenuation factor (corrected)

but K'=cf*K (5)

where:

cf = correction coefficient for local catchment condition based on observed rainfall - runoff data, master unit hydrograph
K = Peak attenuation factor, typical value = 484 (Bedient and Huber, 1992)

From observed 1-hour unit hydrographs, tp can be calculated; and S can be calculated once *y* is obtained from topographic maps of the catchment. From equations (1) and (2) the value of CN' can be calculated. By solving CN', then cfn correction coefficient can be calculated if the CN value was assumed based on the standard runoff curve number tables as a guide (Bedient and Huber, 1992; Wanielista, 1990; Maidment, 1993). From Equation (4), the q_p value and T_R can be obtained from the I hour unit hydrographs, and since the catchment area is known then the constant K' can be calculated. Once the K' constant is solved from Equation (5) the cf correction coefficient can be obtained if an assumed value of K to be equaled to 484 (typical value for SCS Method) was assumed.

Therefore, from the observed unit hydrographs, a master 1-hour unit hydrograph is obtained and the value of tp, T_R, q_p can be obtained and the corresponding correction coefficient for K' and CN' can be calculated for the particular catchment.

Once the correction coefficients' cf and cfn are determined then the estimation of runoff for different land use can be estimated. By using the SCS synthetic unit hydrograph method and the convolution matrix procedure the required synthetic flood hydrographs; are calculated.

3 Results of the Calibration

The Sg. Tasoh catchment as shown in Figure 1 covered an area of 126.0 sq.km. The streamflow gauging site is located at Kg. Tasoh/Kg. Bukit Manek Road Bridge. The maximum length and breadth of the catchment are 15 km and 14 km, respectively. The topography of the northern half of the catchment is fairly mountainous country rising to a maximum height of over 460.0 meters above mean sea level (Bahagian Pengairan dan Saliran, 1988). The remainder part of the catchment is undulating lowlands. About sixty percent (60%) of the catchment is covered by primary forest in the northern and eastern regions.

The land use of the catchment with vegetation cover consists of rubber plantations on the hills and patches of logged over forest towards the north of the catchment. Figure 2 shows the land use map in the catchment.

The soil covers in this catchment consists of soils developed over Sub-Recent Alluvium. The soils are free draining, deep coarse sandy loam to coarse sandy clay loam on flat to gently undulating terrain. At depths below one meter the variegated shale saprolite may be encountered.

The length of Sg. Tasoh is approximately 22.5 km measured from the Kg. Tasoh/Kg. Bukit Manek Road Bridge (gauging site) to the upper most part of the catchment. The average catchment slope in the catchment is about 0.157% (0.1^{o}) and based on the land use and soil cover of the catchment the CN is calculated as shown in Table 2. The land use is mainly rubber plantations for the rural areas, and primary forest. The remaining is undulated condition towards the lowlands. The hydrological soil group for this catchment is between group B and C based on the soil composition. The land use of the catchment that is mainly forest, and rubber plantations, the Runoff Curve Numbers for this catchment are estimated based on weighted CN.

For the purpose of derivation of the master unit hydrograph, it is assumed that the catchment rainfall is homogeneous and the rainfall condition was antecedent moisture condition III.

Table 2 Calculation of weighted CN for Sg. Tasoh Catchment.

Catchment Land use / Weighted Soil Group Based on land use	Forest condition -60% of the catchment. Runoff Curve No.	Agriculture condition - 40% of the catchment. Runoff Curve No.
Group B - 50% of the catchment	55	71
Group C - 50% of the catchment	70	78

The weighted runoff curve number is computed as follows:

CN_W = 0.60*(percentage group B & C CN for forest condition)+0.40*(percentage group B & C CN for agriculture condition)

$$CN_W = 0.60*(0.50(55+70))+0.40*(0.50(71+78)) = 37.5+29.8 = 67.30$$

Use CN = 67.0 for the antecedent moisture condition II.

Therefore, the CN value used in the analysis for the Sg. Tasoh catchment will be 67 for the antecedent moisture condition II. For antecedent moisture condition III, Equation (6) (Chow et.al., 1988) was used.

$$CN(III) = \frac{23CN(II)}{10 + 0.13CN(II)} \qquad (6)$$

The adjusted CN value for antecedent moisture condition III is 82.6, used 83. This CN value is used in the calibration for the correction coefficients.

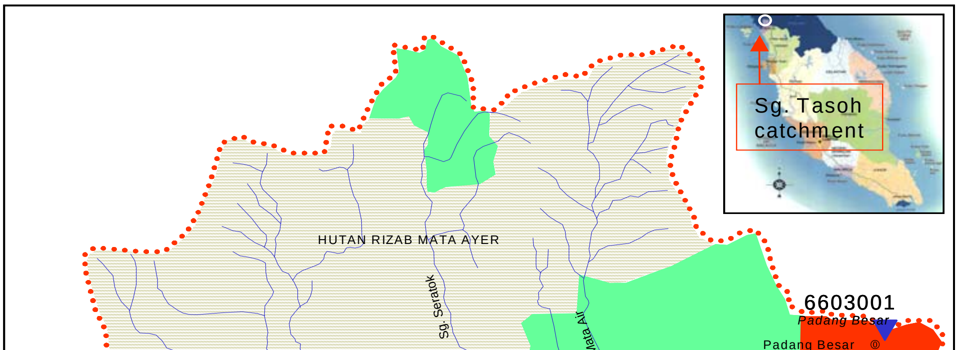

Figure 2 Landuse Map of Sungai Tasoh Catchment.

The September 1975, August 1976 and November 1976, and May 1979 storms were used in the calibration for the correction coefficients of the SCS Method. These storms were selected due to the rainfall and runoff records are readily available and of single storm type. Furthermore, these historical storm events occurred during pre-dam period. This is to ensure that the dam would not be affecting the readings of the streamflow data. The 1975 storm had the shortest time to peak, that is about 24 hours, and the November 1976 storm had the longest time to peak, about 40 hours. The observed peak discharge for these four storms ranges between 10.09 cumecs and 16.30 cumecs.

The rainfall pattern varies between these storms. The August 1976 storm had the longest rainfall duration, that is 33 hours. The rainfall duration for the September 1975, November 1976 and May 1979 storms are 10, 26 and 5 hours as observed from the respective flood hydrographs.

The shape of the observed flood hydrographs is of the broad peak type. The base of the observed flood hydrographs varies from 102 hours to 127 hours. This indicated that the catchment has more undulating area as compared with steep area, and the land use is more of rural and or forested/jungle type.

Each of the observed storms is analyzed individually for the correction coefficients. By separating the baseflow from the flood hydrograph, it derives the direct runoff hydrograph, and using the procedure as described earlier, the Unit Hydrograph and other parameters of the SCS Method for each storm is then computed for the 1 hour storm duration for 1.0 cm of effective rainfall.

Table 3 shows each storm event, and the master correction coefficients for Sg. Tasoh catchment. Figure 3 shows the curvilinear 1- hour unit hydrograph for the storms and Figure 4 shows the curvilinear and triangular 1-hour master unit hydrograph for Sg. Tasoh Catchment.

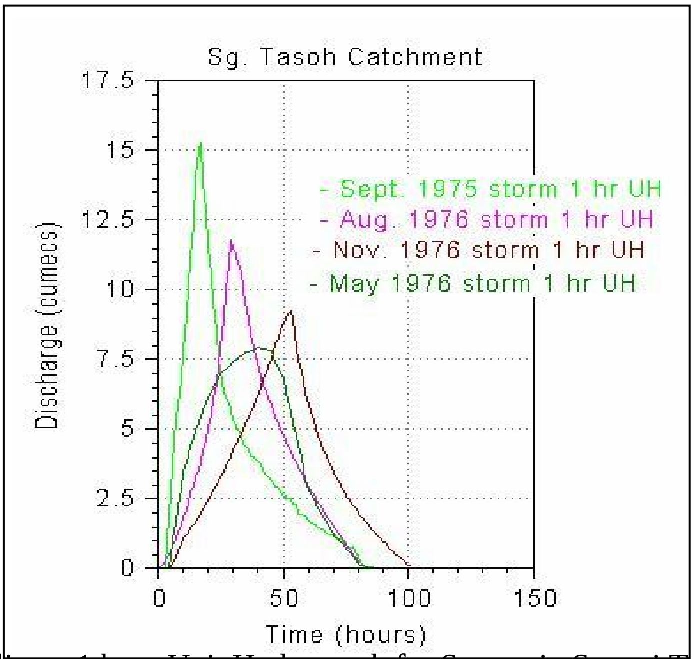

Figure 3 Curvilinear 1 hour Unit Hydrograph for Storms in Sungai Tasoh Catchment.

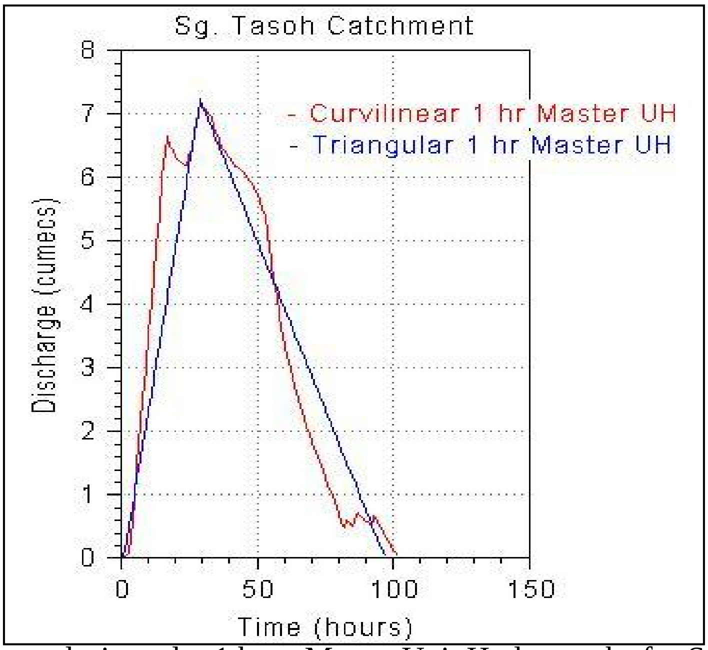

Figure 4 Curvilinear and triangular 1 hour Master Unit Hydrographs for Sungai Tasoh Catchment.

Table 3 Correction Coefficients for SCS Method for Different Storm Events.

Storm Event(s)	**Antecedent moisture Condition III,**	**CN'**	**cfn**	**cf**	**K'**	**K**

	CN					
Sept. 1975	83.00	91.43	1.102	0.988	0.206	0.208
Aug. 1976	83.00	75.59	0.911	1.301	0.271	0.208
Nov. 1976	83.00	52.29	0.630	1.863	0.388	0.208
May 1979	83.00	63.52	0.911	1.203	0.250	0.208
Master Curve	83.00	75.59	0.911	0.798	0.166	0.208

From Table 3, it was observed that the correction coefficient cf (for peak attenuation factor, K) varies between 0.988 and 1.863 for the observed flood hydrographs. The correction coefficient cfn (for CN number) varies from 0.630 to 1.102. The uncorrected CN number varied from the corrected CN number by about 10% except for the November 1976 observed flood hydrograph. This indicates that the CN number estimated initially does not vary significantly from the CN number obtained from the observed flood hydrographs.

Table 4 shows the 1- hour Unit Hydrograph parameters for different storm events. The September 1975 1- hour unit hydrograph has the shortest time to peak, t_P value and the highest q_P value as compared with other 1- hour unit hydrographs. This is probably due to the short duration and high intensity of the rainfall that had occurred throughout the whole catchment and it has longer antecedent rainfall duration as compared with other storm events. The potential maximum retention (S) value of the September 1975 storm event is the lowest, which is due to the longer antecedent rainfall duration that had occurred prior to the high intensity rainfall that causes the peak of the flood hydrograph.

Table 4 1-hour Unit Hydrograph Parameters for Different Storm Events.

Storm Event(s)	**S (mm)**	**q_p (cumecs)**	**t_p (hours)**	**T_R (hours)**	**B (hours)**
Sept. 1975	23.80	15.26	16.50	17.00	28.87
Aug. 1976	82.04	11.78	28.50	29.50	30.40
Nov. 1976	231.75	9.23	52.50	53.00	22.83
May 1979	145.85	7.90	39.50	40.00	48.61
Master Curve	82.04	7.23	28.50	29.00	67.85

The S-Curve method was used to derive the 1- hour unit hydrograph (for 1 cm of effective rainfall) for different storm duration of the storm events. Smoothening of the derived S-Curves and the 1- hour unit hydrographs was unavoidable due to the harmonic oscillation effect at the tail end of the curves.

4 Comparison of_Peak Discharge and Volume of Storm Hydrograph Derived Using SCS Method with Hydrological Procedure No.11 (HP11) by (JPS).

The peak discharge and the volume of the synthetic storm hydrograph using the calibrated correction coefficients of the SCS Method is used to compare with the synthetic storm hydrograph derived using HP No. 11 of Jabatan Pengairan dan Saliran Malaysia (Drainage and Irrigation Division, 1976). The 50-years Return Period of excessive or effective rainfall of 7.60 inches for 5 hours storm duration is use in the comparison of the SCS Method with HP No.11. The HP11 method was used in the comparison study is because it uses the Unit Hydrograph method to calculate for the synthetic storm hydrographs. The rainfall temporal pattern from HP1 (Drainage and Irrigation Department, 1994) was used in the SCS Method. The results of the two methods are as shown in Table 5.

Table 5 Comparison of Calibrated SCS Method with HP11 Using 50 –Years ARI 5 Hours Effective Rainfall.

Method Used	Peak Discharge (cumecs)	% of difference for Peak Discharge against HP11	Volume in millions (m^3)	% of difference for Volume against HP11
SCS Method	138.0	30.70	24.84	0.92
HP No. 11	199.0	-	25.07	-

The percentage of difference for peak discharge between using SCS Method with HP11 is about 30.70%. The difference in peak discharge is significant for the design of hydraulic structures such as culverts, bridges, and weirs. The volume of the storm hydrograph, which has a difference of 0.92%, is insignificant, and it is not an important factor when designing hydraulic structures, unless it is use to determine the duration of inundation for a tidal affected area. The significant difference for the peak discharge can be attributed to the fact that the HP11 method tends to generalize the characteristic of a catchment to a single grouping type. The HP11 generalize catchment characteristics into 3 grouping type, that is, whole catchment very steep and covered with virgin jungle; upper catchment very steep and covered with jungle, lower catchment reaches hilly and covered predominantly with rubber; and whole catchment undulating with variable vegetation including jungle, rubber and agricultural development.

5 Discussion & Conclusion

The Master Unit Hydrograph for the Sungai Tasoh catchment is determined from observed storm events. It is then use in the calibration of the correction coefficients of the parameters of the SCS Method for Sungai Tasoh catchment. Based on the overall comparison study of the SCS and HPII methods, it can be concluded that the SCS Method gives a better estimation of the peak discharge, time of rise and volume of the storm hydrograph. This is because the SCS Method was calibrated (correction coefficients) based on observed flood hydrographs of the catchment.

By applying the calibrated correction coefficients of the SCS Method, the synthetic storm runoffs from different storm duration, and return periods' can be estimated. For land use changes in the catchment, the runoffs can be estimated by changing the CN values. The convolution matrix procedure is use to calculate the runoffs for different storm duration by using rainfall temporal patterns obtained from HP1 (Drainage and Irrigation Department, 1994). More storm events should be used to calibrate the SCS Method for Sungai Tasoh catchment. By using more storm events for the calibration, the master unit hydrograph for Sungai Tasoh will be more accurate representing the catchment.

Computer models such as HEC1 or HEC-HMS make use of SCS Method as an optional method to simulate runoffs from rainfall data. By inputting the master unit hydrograph ordinates into the computer, the computer can simulate runoffs for different land use changes, storm duration and return periods.

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