Computation and Optimization of Snyder's Synthetic Unit Hydrograph Parameters

G. Thapa and N.T.S. Wijesekera

ABSTRACT

In Sri Lanka, the availability of Snyder's Synthetic Unit Hydrograph (SSUH) parameters are reported only in the Irrigation Department Guidelines and those are limited to only 19 locations. The present study is to determine the SSUH parameters and their applicability to the Karasnagala watershed (52.58 KM2). 60 events corresponding to both North East and South West monsoons during the 1971-1989 period were selected for the model calibration and verification. Considering a balanced representation of both seasons, 30 events were selected for model calibration while the rest were taken for model verification. Events were separated using a minimum inter-event time of 2 days. Effective rainfall corresponding to each event was determined using Phi-Index and incorporating the baseflow separation with the use of Concave method. A one day triangular SUH computed for each event was then converted to curvilinear SUH with the help of SCS dimensionless hydrograph. Mean Ratio of Absolute Error (MRAE) was chosen as the objective function for the evaluation of the total, high, intermediate and low flow estimated by the model. Model verification used the averaged parameter values optimized for each event during model calibration. Averaged calibrated parameters Ct and Cp for Attanagalu Oya Basin at Karasnagala were 3.75 and 0.38 respectively with MRAE value of 0.2. The results obtained were further compared with the recommended ID guideline parameters. The value of Ct and Cp can be applied to the other ungauged areas of the Attanagalu river basin and regions having similar characteristics and consider as the basis for further studies with shorter temporal data resolution.

KEYWORDS: Ungauged, Events, Concave method, Snyder's Synthetic Unit Hydrograph, Parameters Ct & Cp, Sri Lanka.

1. Introduction

Engineers working in new developments often need to work with ungauged watersheds. In Sri Lanka out of 103 river basins, many are not gauged and there are only about 40 river gauges maintained by the Department of Irrigation. Hence most development planning works require models to estimate streamflow at various locations. Calibrated and verified model parameters for gauged watersheds are at rarity in Sri Lanka. There are no reviewed publications to confidently use available model parameters of gauged watersheds. Reviewing approximately 100 Sri Lankan studies on water resources and modeling, Wijesekera (2010) revealed that there exists only very limited hydrological modeling efforts. Hence, there is a gap when attempting to extrapolate model parameters from gauged to ungauged watersheds. Present work is an attempt to establish the Snyder's Synthetic Unit Hydrograph (SSUH) parameters for the Karasnagala watershed (Figure 1) with the aim of facilitating reliable parameters for the use in similar ungauged locations. SSUH was selected for many reasons. SSUH is a method commonly applied to generate direct runoff hydrographs in many engineering applications (Mays, 2004). In a study conducted by Salami (2009) on Lower Niger River Basin with catchment area of 906 km2, different methods like SCS Dimensionless Unit Hydrograph, Snyder, and Clark methods were applied to develop a Synthetic Unit Hydrograph (SUH) and found that the peak flow value obtained from Snyder's method was much closer to the observed values. Limantara (2009) in a study on Garang watershed in Indonesia having a catchment area of 73.5 km2 reflected that the Synthetic Unit Hydrograph (SUH) has been a great utility when planning hydraulic structures in a field with data deficient situation.

Miller et al. (1983) in their studies suggested that the Snyder's non-dimensional constants Ct and Cp can vary in the range of 1.01-4.33and 0.23-0.67 respectively. Similarly, Hudlow and Clark (1969) proposed Ct and Cp value can range from 0.4-2.26 and 0.31-1.22 respectively.

The aim of the present work is to calibrate and verify SSUH parameters for Karasnagala watershed, evaluate the performance of SSUH model and to make recommendations on applications.

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2. Study Area and Data

Karasnagala is a sub-watershed of Attanagalu Oya river basin. It is in the Gampaha district, falling inside of the Western province of Sri Lanka. The catchment which is approximately 52.58 km2 mainly consists of cultivatable land (72.82%) as reported by Perera, (2010). Data of daily temporal resolution from 1971 to 1989 were available for the streamflow gauging station at Karasnagala and for the two rain gauging stations at Vincit & Karasnagala (Figure 1). 1:10,000 Topographic maps from the Department of Survey, Sri Lanka were used for the study. Thiessen averaged annual rainfall and observed streamflow of the watershed amounted to 258 and 190 mm respectively.

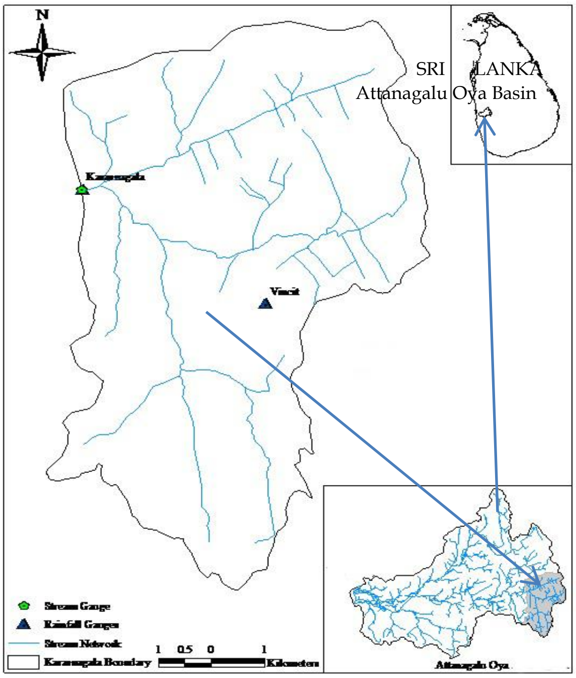

Figure 7: Map of Study area

3. Methodology

Dunkley (2008) with references to published studies and using MIT from 15 minutes to 24 hrs, showed that longer MIT values would be useful for the identification of independent events because of extensive intra-event gaps. The popular empirical equation for N days proposed by Linsley et al. (1958), was used to compute the Minimum Inter-event Time (MIT). As suggested by Pettyjohn and Henning (1979), the value of "N" computed for the study area was 2 days. Miller et al. (1983) used samples ranging from 12 to 27 events for model calibration and verifications from different catchments. In the present work, a total of 60 events were separated and the first 30 were used for model calibration while remaining 30 were taken for verification. Longest duration of events of calibration and verification dataset was 9 and 8 days respectively. Respective event distribution corresponding to Maha and Yala seasons were 57% and 43% for calibration events while the same were 53% and 47% for verification events.

Baseflow was separated using Concave Method and as per recommendations in Pettyjohn and Henning (1979). Baseflow separation of all 60 events was carried out while carefully observing both the normal and semi logarithmic plots of streamflow. A spreadsheet model balancing the effective rainfall and direct runoff was developed to compute rainfall loss by Phi-index method (Chow et al. 2013). Another spreadsheet model was developed to compute the Synthetic Unit Hydrograph and to Calibrate the regional parameters (Ct and Cp) for each selected events.

Geometric parameters were derived from the Arc-GIS and Empirical equations 1, 2 and 3 were used to compute the, Basin lag (tp), standard duration (tr) for the watershed and Peak discharge (Qp) of the standard SUH

$$tp = 0.75 * Ct * (Lc * L)^{0.3} \quad (1)$$

$$tr = \frac{tp}{5.5} \quad (2)$$

$$Qp = \frac{2.75 * Cp * Q * A}{tp} \quad (3)$$

where,

Lc = distance in kilometers from the outlet to a point on the stream nearest the centroid of the watershed area

L = length of main stream in kilometers

A = area of watershed

Q = discharge in m3/s

Since the base data were of daily temporal resolution, the SSUH considered 24 hours as the required duration. The triangular UH was then converted to a curvilinear unit hydrograph with the help of SCS dimensionless hydrograph (Ritzema, 1984) while maintaining the area under the hydrograph as one unit. Effective rainfall computed by the first spreadsheet model was then applied to generate Direct Runoff (DRO) hydrograph. In this model the regional parameters for each calibration event were optimized to fit observed and computed hydrographs. Objective function selection was guided mainly by WMO (1975), and Wijesekera & Musiake (1990). Mean Ratio of Absolute Error (MRAE) was taken as the primary objective function while Ratio of Absolute Error to Mean (RAEM) was also applied during optimization and verification to cross verify the performance level as shown in equation 4 and 5. The modelling efficiency values pertaining to peak discharge, time to peak, base time and streamflow volume were also compared during each optimization and verification.

$$MRAE = \frac{1}{n}\sum \frac{|Qc - Qo|}{Qo} \text{..........(4)}$$

$$RAEM = \frac{\sum|Qo - Qc|}{n\overline{Qo}} \text{ ... ... (5)}$$

Where Qo = Observed discharge
Qc = Computed discharge
n = Number of events

In case of event based modelling, the calibration event parameters need averaging to apply for model verifications. Hence the calibrated regional parameter values were averaged to verify the performance of each verification period events with the averaged calibration parameters. This practice is the same as that reported in the studies carried out by Miller et al. (1983).

4. Result

Optimized Ct and Cp obtained from calibration events and sorted for peak discharge of each event are as shown in Figure 2a and Figure 2b.

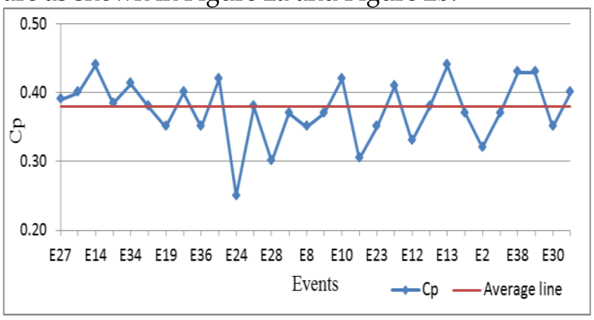

Figure 2a: Variation of Cp in each calibration event

Averaged value of Ct was 3.75 while the same for Cp was 0.38. Standard deviation of the Ct and Cp values during calibration were 0.55 and 0.04 respectively.

The MRAE during calibration varied between 0.03 and 0.44 while the same for RAEM varied between 0.03 and 0.56. Model verification results showed that averaged Ct and Cp parameters produced a larger error compared to individual event optimization (Figure 3a & 3b).

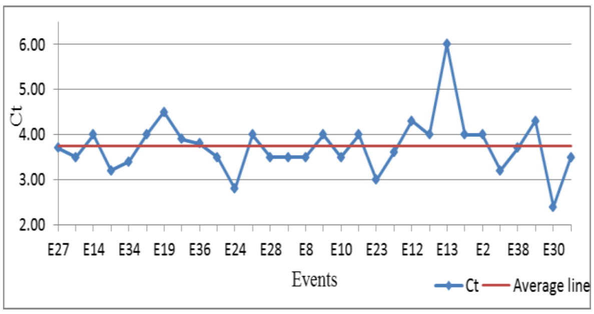

Figure 2b: Variation of Cp in each calibration event

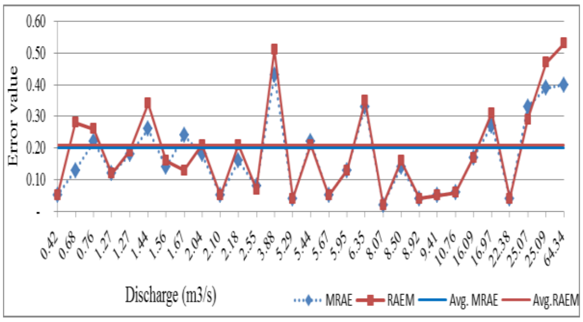

Figure 3a: Variation of MRAE & RAEM in each calibration event

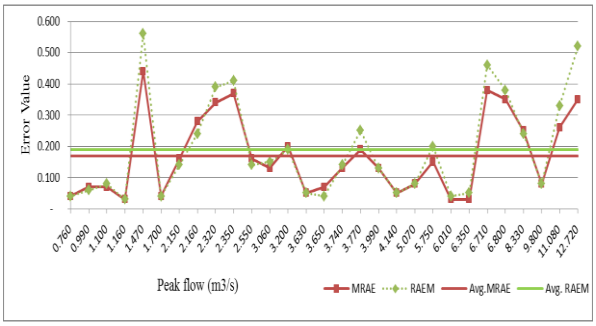

Figure 3b: Variation of MRAE & RAEM in each verification event

Averaged value of MRAE and RAEM during verification were 0.20 and 0.21 respectively. Hydrograph matching samples during calibration is shown in Figure 4 while the same corresponding the verification are shown in Figure 5. The events were classified as high, medium and low based on peak flow. The respective simulated peak flow value in calibration and verification ranges were 0.76 m3/s-36.63 m3/s and 0.38m3/s –62.87m3/s. The most frequent values of Ct and Cp for high flow were 4.3 and 0.42 respectively. The same for medium flow were 4 and 0.37, while for low flow events, the range was 3.5 and 0.35.

All verification events were then subjected to individual optimization in order evaluate the difference between the behavior of parameters with each event and with a set of events. And on the calibration events averaged Ct and Cp were applied to check the overall performance of the model.

The summary of output from model calibration and verification and model estimation is in Table 1.

The computed value of average loss rate from a set of 60 events was 1.20mm/hr. (loss rate variation in the calibration events was between 0.18 and 2.86 mm/hr., while the same for verification events were 0.03 and 3.12 mm/hr). The average loss rate during Maha and Yala season was 1.32 mm/hr. and 2.52mm/hr. respectively.

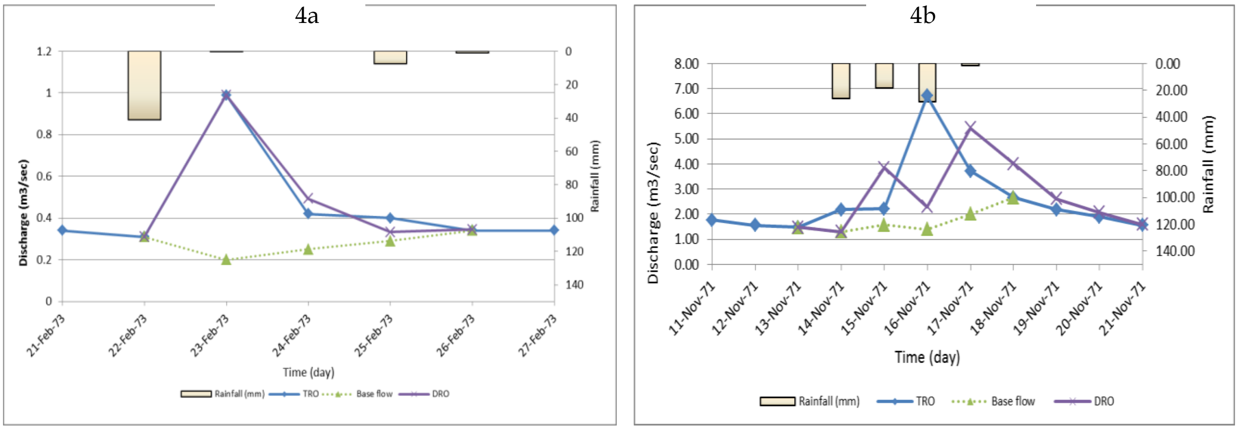

Figure 4: Hydrographs during calibration with sample from very good matching (4a) and poor matching (4b)

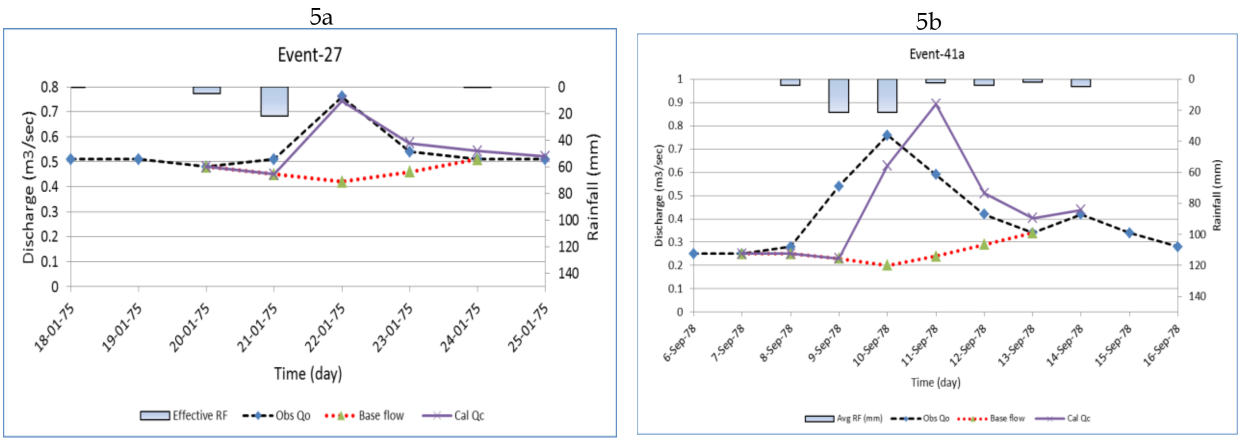

Figure 5: Hydrographs during verification with sample from very good matching (5a) and poor matching (5b)

Table 1: Summary of model performance result

Details	Model Calibration and Verification		Model Estimations	
	Calibration (30 Events)	Verification with Averaged Ct & Cp (30 Events)	Applying Averaged Ct & Cp on Calibration data set (30 Events)	Optimization of Ct & Cp on verification data set (30 Events)
Averaged MRAE	0.17	0.20	0.21	0.18
Averaged RAEM	0.19	0.21	0.22	0.20
Averaged RAE Qp	0.16	0.17	0.18	0.18
Averaged RAE Tp	0.06	0.10	0.06	0.10
Ct	2.4-6.0	3.75	3.75	2.0-4.0
Cp	0.25-0.44	0.38	0.38	0.3-0.45

5. Discussion

In course of analysis, it is confirmed the suitability of Snyder's model to simulate flow discharges in Attanagalu Oya. A comparison on discharge data and modelled output hydrograph graph also showed good model performance during model calibrations and verifications with a MRAE value of 0.20. Comparison with the values from the Irrigation Guidelines recommended values of Ct and Cp for the closest location of the adjacent river basin approximately 22 km away are 3.76 and 0.55 respectively. And the values are pretty close to the result from simulation of SSUH model.

- A systematic model calibration and verification demonstrated a methodology to carryout parameter evaluations from time to time as and when more data becomes available.
- The modelling effort showed the need to consider the range of flows to obtain the appropriate set of parameters.
- Modelling showed that even though each individual events are calibrated, a representative value has to be identified for verification and for guidelines (unless there is a very large set of observations).
- The results from the model depends on the loss rates and baseflow separation, hence it is important to consider the effects of same on the parameters.
- The data resolution was found too coarse as the most available data are daily, This factor also should be investigated.
- The average Ct and Cp values of 0.38 and 3.75 respectively showed a very good reproduction of observed event runoff for water infrastructure designs.
- The averaged parameter values of Ct and Cp can be applied to the other ungauged areas of the Attanagalu Oya river basin and other regions having similar catchment characteristics.
- During the studies it has been realised that the value of Cp is more sensitive than Ct while computation of discharges and hydrograph matching. While the standard deviation shows that the Cp value merely deviates from the mean of Optimised Parameters.
- These parameters can be considered as the basis for further studies on the region with shorter temporal data resolution.

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7. References

Chow, V.T., Maidment, D.R & Mays, L.W.,(2013), Applied Hydrology (7th ed). New Delhi, India: Mc Graw Hill Edu-cation. New York.
Hudlow MD, Clark DM. Hydrological synthesis by digital computers. *J Hydrol Div ASCE 1969*, 95(3), 839-60
Limantara,L.,M.,(2009). Evaluation of Roughness constant of river in Synthetic Unit Hydrograph. *World Applied Sciences Journal*, 7 (9), 1209-1211.
Linsley, R.K., & Kholer, M.A.(1951). Predicting the Runoff from storm rainfall (Report no.34).Weather Bureau, U.S Department of Commerce.
Mays, L.W., (2004). Water Resources Engineering. John Wiley and Sons Inc.
Miller, A.C., Kerr, S.N., Spaeder, D.J., (1983). Calibration of Snyder Coefficients for Pennsylvania. *American Water Resource Association*, Vol.19.
MUSIAKE, Katumi, and Sohan WIJESEKERA. "研究速報: Stream Flow Modelling of Sri Lankan Catchments (1): Mabaweli River Catchment at Peradeniya." (1990).
MUSIAKE, Katumi, and Sohan WIJESEKERA. "研究速報: Stream Flow Modelling of Sri Lankan Catchments (2): Kalu River Catchment at Putupaula." (1990).
Pettyjohn, W.A., & Henning, R. (1979). Preliminary Estimate of Ground Water Recharge Rates, Related Streamflow and Water Quality in Ohio (Report No.552). Ohio, USA: Ohio State University, Department of Geology and Mineralogy.
Ritzema, H. P. (1994). Drainage Principles and Applications. Wageningen, The Netherlands: International Institute for Land Reclamation and Improvement.
Salami, A. W., (2009), Evaluation of methods of Strom Hy-drograph Development, *International e-Journal of Engineer-ing Mathematics*: Theory and Application, Vol.(6), pp.17-28.
Wijesekera, N.T.S. (2010a). Surface Water Resources and Climate Change. National Science

Foundation Ministry of Irrigation and water resources management, Sri Lanka.
WMO. 1974. Guide to Hydrometeorological Practices, 3rd edition. World Meteorological Organization: Geneva. (Helfer, Lemckert & Zang, 2012). Impacts of climate change on temperature and evaporation from a large reservoir in Australia. *Journal of Hydrology*, *475*, 365–378