研　究　速　報

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Stream Flow Modelling of Sri Lankan Catchments (1)
——Mahaweli River Catchment at Peradeniya——
スリランカの河川流域の流出機構のモデル化 (1)
——マハベリ川について——

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1. Introduction

This is the first of a two part series presenting the stream flow modelling of two Sri Lankan catchments. Part one describes the details in the modelling of the Mahaweli river basin while discussing the model construction, parameter optimisation and the inclusion of spatially varied rainfall. Part two consists of the application of the model to the Kalu river basin and the modifications made during application.

The island of Sri Lanka is located in the Indian Ocean between the latitudes 5°55′-9°50′N and longitudes 79°42′-81°52′E. Coastal and Nothern regions of the island are flat while the Southern and Central regions are hilly and mountainous. Sri Lanka has two pronounced rainy seasons. One is due to the South-West monsoon from May to August and the other is due to the North-East monsoon from November to February. Mahaweli is the longest river starting from the central hills and flowing through the North-East of the island ending at Trincomalie. The Mahaweli catchment at Peradeniya (1167km^2) is located in the central hills (Fig 1.1). As there has been no major development activity prior to the study period (from 1969-1980) the area above Peradeniya is treated as a virgin catchment. In the present work, the daily stream flow at Peradeniya is simulated using daily rainfall data collected at four stations. Daily pan evaporation data from 1978-1986 at two stations, the topographic and land use maps were also available (Fig. 1.1).

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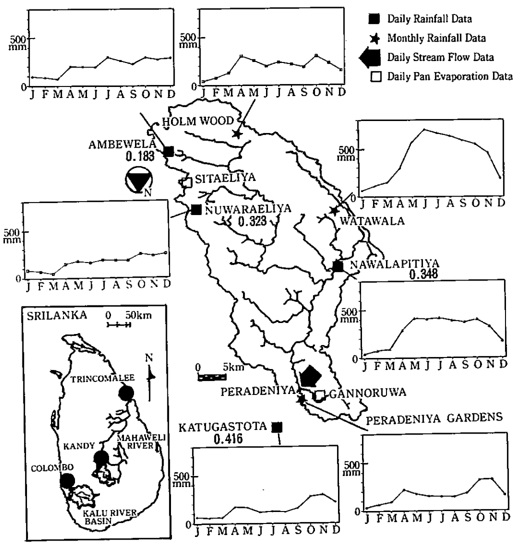

Fig. 1.1 Monthly Average Rainfall and Optimised Rainfall Station Weights

2. Model

A simple tank model (Sugawara 1961) with four tanks (Fig 2.1) was used to simulate stream flow and the Powell search technique (Powell 1965) was incorporated to optimise model parameters. Mean square error of the logarithms of discharges was taken as the objective function since the logarithms reflect the differences in both high and low flows. The optimised parameters were evaluated using,

1. The Ratio of Absolute Error to Mean, which had been used by the World Meteorological Organization (WMO 1975) for numerical comparison, and which is defined as

$$\left(\frac{\sum |y_o - y_c|}{n\bar{y}_o} \right)$$

where y_c is the computed discharge; y_o is the observed discharge; $\bar{y}_o$ is the mean of observed discharges and n is the number of observations;

2. The graphical comparison of semi-log plots of outflow hydrographs and flow duration curves;
3. Realism of optimised parameters and the storages pertaining to the tank structure.

In the computer model the following conditions were imposed on the space of movement for the model parameters:

1. Condition of continuity.
2. Preservation of tank side outlet positions.
3. Positive values for all parameters.

3. Application

Weighting parameters were assigned to the rainfall stations to incorporate the spatial variability of rainfall. As the tank structure consists of 13 parameters, the number for the Mahaweli basin calculations totalled 17. Since the model calculations require a considerable amount of time in optimising 17 parameters, the tank parameters and station weights were treated as two sets. Then optimisation was carried out in a cyclic manner optimising one set at a time while keeping the other constant. The optimisation procedure is shown by the flow chart in figure 1.3.

The model parameters were rescaled to aid smoothening of the objective function surface during optimisation (Pilgrim 1975, Kadoya 1980). Data from 1969-1973 were used for model calibration while the data from 1976-1980 were taken for verification. The Data for years 1974 and 1975 resulted incompatible values during water balance studies using uniform rainfall concept and hence were not used in the calculations. At the beginning, an estimate of the catchment lag was obtained by trial and error, incorporating uniform rainfall with an approximate set of tank parameters and using the ratio of absolute error to mean as criterion for comparison. Inputs for estimation of parameters consist of the catchment lag, the initially assumed parameters for the model, the monthly evaporation indices, and the rainfall and stream flow data.

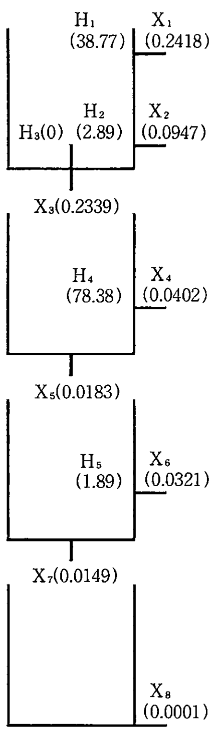

Fig. 1.2 The Simple Tank Structure with Optimised Parameters

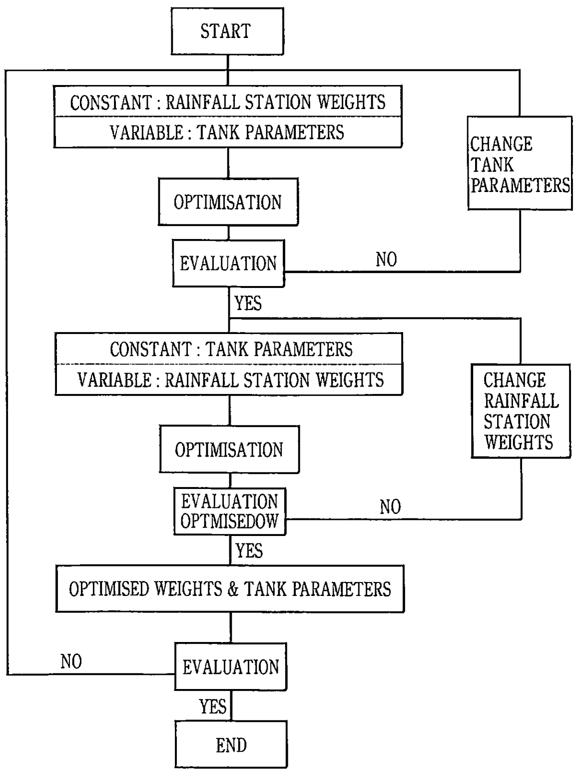

Fig. 1.3 Cyclic Procedure for Optimisation of Rainfall Station Weights and Tank Parameters

The pan evaporation data at both stations showed a similar pattern in monthly fluctuations and this similarity was used to calculate average evaporation indices for the entire basin. The average annual water loss during the estimation period was apportioned using the evaporation indices to calculate the daily evaporation values for the model in both estimation and verification periods. Tank storages at the commencement of calculations affect the model predictions at the early stages and this period is referred to as the warming up period of the model. The model warms up faster if the initial storages could be estimated properly. In this study, five rotational calculations of the estimation data set resulted stable storages at a desired point of time and these were used as initial storages for the parameter estimation.

Initially, tank parameters were optimised assuming a uniform spatial variation of rainfall. The station weights were then optimised keeping the tank parameters constant. These calculations were repeated cyclically until the evaluation criteria were satisfied. The convergence of the model during optimisation was dependent on the initial estimations of tank parameters. Therefore a trial and error improvement of initial parameters was used along with the evaluation criteria. The ratio of absolute error to mean in cases assuming uniform and spatially varied rainfall were 0.2733 and 0.2399 respectively, showing an improvement of 11% in the matching of observed and calculated stream flows. The outflow hydrographs for the year 1970 in the calibration period for above two cases are shown in Fig 1.4. The optimised rainfall station weights along with the temporal distribution of rainfall within the year are shown in Fig 1.1. The outflow hydrographs for the years 1971 and 1978 in calibration and verification periods are shown in Fig 1.5.

4. Concluding Remarks

Stream flow modelling using a tank model and parameter optimization by a search technique considering spatial variability of rainfall is presented. In this study the rain gauging station weights are also treated as parameters and are optimised along with the model parameters. The agreement of the computed results and the observed data significantly improved with the introduction of spatial variability of rain. The optimized weighting parameters for rain gauging stations seems justifiable when compared with the rainfall distributions and the location of stations. The optimisation resulted in converging to local minima depending on the initial conditions and as such no unique parameters could be obtained. This is considered as due to the large number of parameters in the model, the noise present in the real data and the imperfections in the objective function because of the imposed conditions for parameters. Calculations during the estimation period showed that the average annual water balance values provided better results than when yearly values were used. This showed that the evaporation values are not very critical in the model outputs. The adopted procedure for the calculation of evaporation indices showed to be adequate in calculating stream flows.

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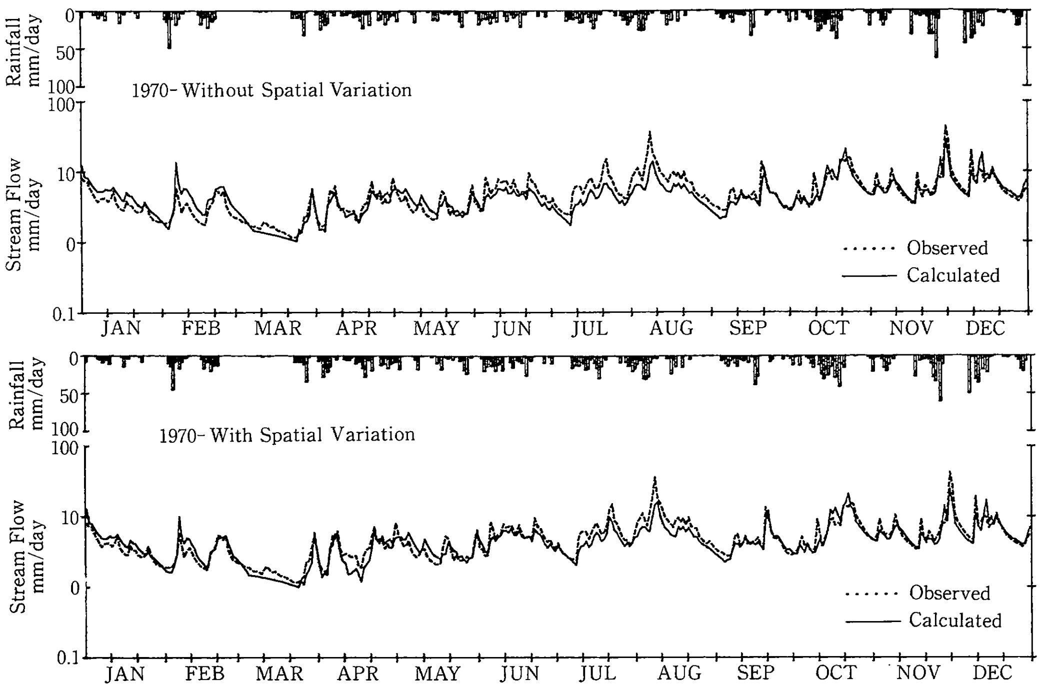

Fig. 1.4 Hydrograph Comparison with and without Spatial Variation of Rainfall

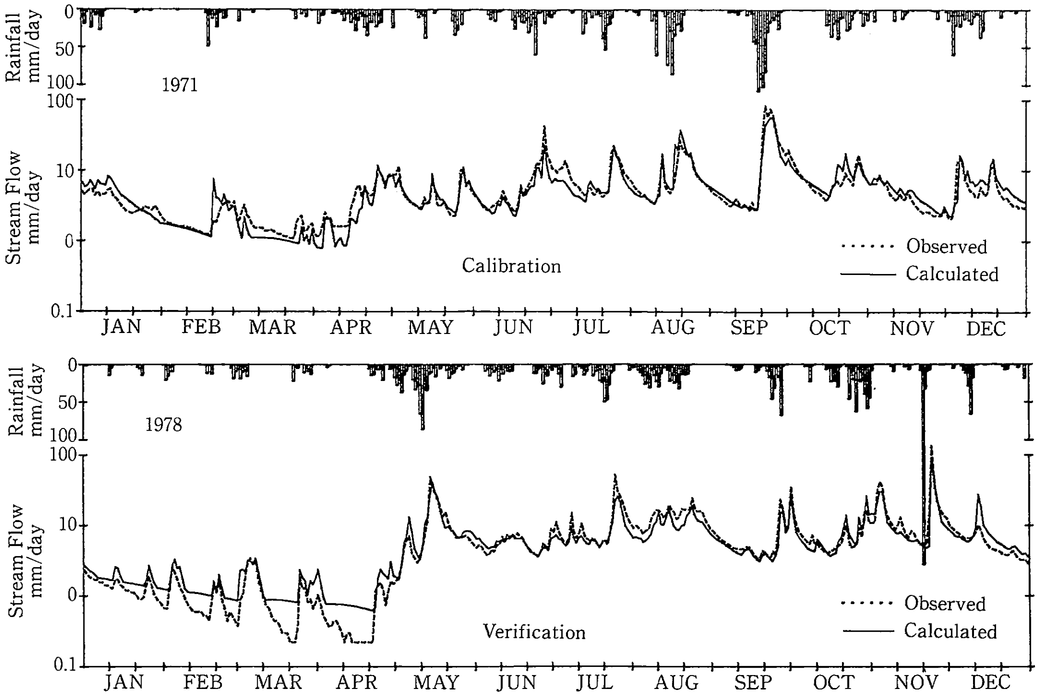

Fig. 1.5 Observed and Calculated Hydrographs during Model Calibration and Verification considering Spatial Variation of Rainfall