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Simulation of Catchment Rainfall-Runoff Using Area Function and Tank Model

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1. Introduction

Tank model has a simple clear concept and is easy to apply, but is difficult to incorporate catchment spatial heterogeneity. Using catchment area function to describe the topography and rainfall distribution, a lumped catchment is derived. The catchment response can be determined by convoluting the hillslope response and area function[1]. To examine this idea, using tank model to simulate hillslope response and Kinematic model to route river flow, a catchment rainfall-runoff model is developed in this study, where the lateral inflow $q(x,t)$ to the river is given by

$$q(x,t) = f_h(x,t)\,A(x) \tag{1}$$

where $f_h(x,t)$ is hillslope response, and $A(x)$ is the area function.

2. Study Catchment and Area Function

Seki river which lies in Tohoku district is selected as the study area. This catchment is simulated above the discharge-gauge station with an area of 703 km^2. The topography of the catchment distinctly varies from upper steep mountain to lower flat plain. Area function is extracted from 250 m mesh DEM data (from Japan Geographical Survey Institute) with threshold area of 2.5 km^2. Fig. 1 shows the catchment and locations of rainfall and discharge stations. Fig. 2 shows the area function above the discharge station.

3. Methodology

3.1 Lumped catchment

Area function gives the accumulative area distribution with respect to flow distance. Considering a flow path interval Δx at distance x, the catchment area accumulated in this interval is simplified as hillslope elements. On each flow path interval, the hillslope response enter the river as lateral inflow. The lumped catchment in the present study uses an "equivalent" single river. Length of the "equivalent" river is the maximum length of actual river, other parameters for Kinematic wave model are the same as that of real main river. Maximum river length of the catchment simulated is 57.2 km. Flow path interval is less than 600 m, and the number of flow path intervals is 138, i.e. 138 tank models are used to simulate individual hillslope responses, and same parameters are used for all tanks.

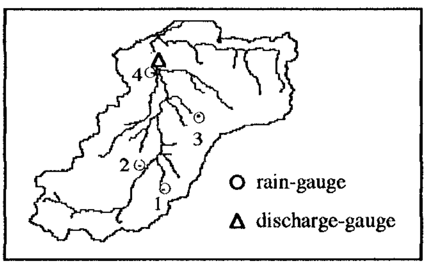

Fig. 1 Seki river

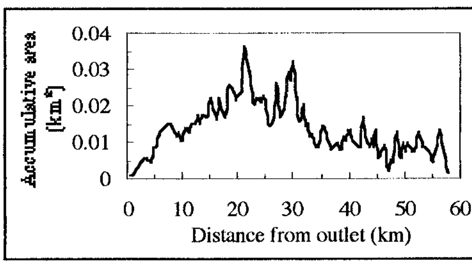

Fig. 2 Area Function above discharge-gauge

3.2 Rainfall distribution

It is necessary to consider rainfall distribution for large catchments and when orographic rainfall occurs. If the number of rain-gauge stations in more than one, the rainfall distribution can be given by Thiessen polygons. Similar to area function, the rain-area distribution can be derived for each rain-gauge station. At any point in catchment (the distance from this point to outlet is x), the rainfall value $r(x)$ is given by

$$r(x) = \sum_{i=1}^{n} r_i A_{r_i}(x) \Big/ \sum_{i=1}^{n} A_{r_i}(x) \tag{2}$$

where, r_i is the rainfall at ith rain-gauge, A_{ri} is the rain-area function of ith rain-gauge, n is the number of rain-gauges.

3.3 Hillslope response and river routing

Keywords : rainfall-runoff model, hillslope response, area function, tank model, river routing
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Two tanks and three tanks simple models are used as hillslope response model for each hillslope segment in this study. Kinematic model is used for river routing and solved using explicit finite difference method.

4. Application

Based on the available data [2][3], the flood of Seki river during July 11 to July 12, 1995 is simulated. Fig. 3 shows the rainfall at four stations (from Japan Meteorological Association). Fig. 4 shows the parameters used in three tanks model and the comparison of observed flood hydrograph with simulated flood hydrograph. Fig. 5 shows the case of two tanks model. It can be seen that simulated hydrograph shows very good agreement with the observed one, even in case of using the simplest tank model as hillslope response model.

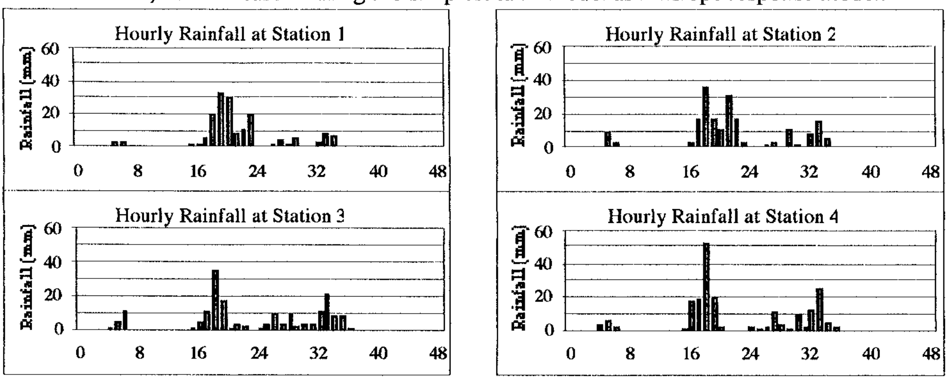

Fig. 3 Hourly Rainfall (July 11 - 12, 1995)

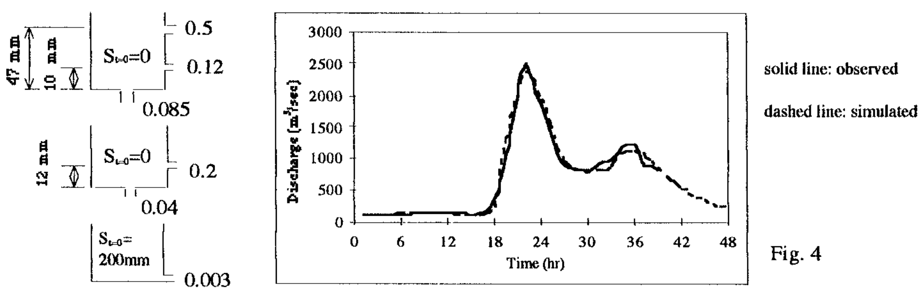

Fig. 4

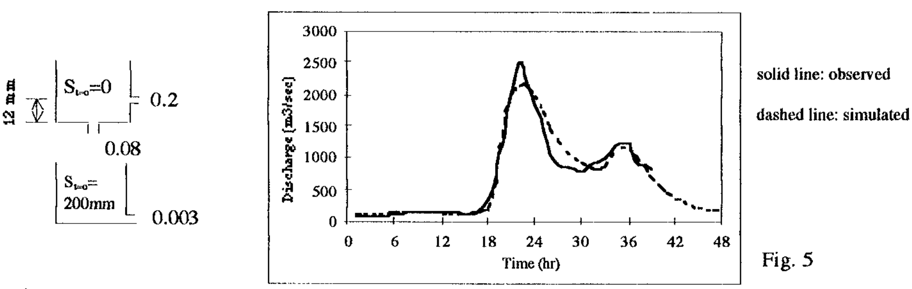

Fig. 5

5. Conclusion

For hydrologic modeling, description of catchment spatial variation is very important. Area function concept can easily and effectively describe catchment spatial variations for lumping hillslope response. The present study confirms the effectiveness of using the area function with a hillslope response model and rainfall distribution to obtain a representative hydrologic model. This concept can be extended to accommodate other spatial heterogeneities, such as slope, land use, soil type, etc.

Reference

(1) Yang D., Herath S. and Musiake K., Analysis of geomorphologic properties extracted from DEMs for hydrologic modeling, Annual Journal of Hydraulic Engineering, JSCE Vol. 41, pp105-110, 1997.

(2) Ashida, K. and Tsujimoto T., Characteristics of disasters in river basin of Tohoku District due to H7.7.11-7.12 storm, Symposium on River Disaster, Hydraulic Engineering Committee, JSCE, March 17, pp 37-58, 1996 (in Japanese).

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