Rainfall-Runoff Modelling of Catchments in Urajiro River Basin Using A Conceptual Model

浦白川流出試験地の降雨―流出概念モデル

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Abstract

The conceptual mathematical models are popularly used for rainfall runoff modelling of a catchment. A conceptual model has been applied for rainfall runoff modelling of the experimental catchments of NIED located in Chiba Prefecture - the catchment up to Kakinokidai (are 0.15 sq. km.) and the catchment up to Tsukizaki (area 9.04 sq. km.). The model results are reasonably good.

Key words : rainfall, runoff, conceptual model, experimental basin
キーワード：降雨，流出，概念モデル，流出試験地

1. Introduction

The rainfall runoff modeling of a catchment using a conceptual model lies intermediate between the detailed physically based models and the empirical models. The term "conceptual", is used to denote those models which rely on simple arrangement of interlinked conceptual elements, each representing a segment of the land phase of the hydrologic cycle. The most commonly used element in a conceptual model is the storage.

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Each of these unequal sized storage usually has one input and one or more outputs and is used to represent a catchment storage, e. g. surface detention, soil moisture etc. The linear reservoirs and channels are used for routing purposes. The modelling basically consists of a set of rules which govern moisture flow from one element to another. Since this is a non-iterative accounting procedure, these models are computationally very efficient.

The conceptual models were initially developed for small homogeneous areas. However, they have been successfully applied to basins having wide variations in topography and vegetation and large area. The input data requirements for these models are quite modest and can be easily met with. Ciriani et al (1977) and Blackie & Eeles (1985) give a lucid discussion on philosophy and applications of these models.

A conceptual model has been used for rainfall-runoff modelling of two experimental catchments of NIED, JAPAN. These catchments are located in the Urajiro basin in Chiba Prefecture.

2. Description of the model used

In the model used in the present study, the catchment is represented with the help of three storages. The first storage termed as surface storage, represents the water stored on the catchment surface. It has a maximum storage capacity given by S_{max} (mm). The second storage represents the catchment soil moisture storage and has a maximum water holding capacity given by C_{max} (mm). The third storage represents the ground water zone. It may be mentioned that most of the existing models make use of similar arrangement of linear reservoirs with varying degrees of complexity.

The rainfall is input to the surface storage. The water may leave this storage through evaporation, infiltration or overland flow. The moisture content of this storage at any time is denoted by SURF. If SURF $> E_p$ (potential evaporation in mm/hr), the actual evapotranspiration is at the potential rate else evapotranspiration (ET) takes place from the lower storage at a lesser rate. The infiltration of water from this storage to the soil storage takes place at the rate INF :

$$INF = (1 - C_{soil}/C_{max}) * F_{inf} \text{ if SURF} > 0$$
$$= 0 \text{ otherwise} \tag{1}$$

where Finf is a factor (mm/hr) controlling the infiltration rate. It may be noted that when $C_{soil} = C_{max}$, INF will be zero. One may visualize that in this event the surface and

the soil moisture storages have merged and the downward movement of moisture is computed as described below.

If at any instant $SURF > S_{max}$, the excess water over S_{max}, flows as overland flow (OF). The OF is routed through a linear reservoir LR 1 with time constant K_o.

The water infiltrated from the surface storage enters the soil storage. The outflow from this storage can take place through ET losses, interflow or recharge to the groundwater zone. If the surface storage is empty, ET takes place from the soil storage at a rate E_a given by

$$E_a = C_{soil}/C_{max} * E_p \tag{2}$$

and C_{max} is depleted by $E_p * dt$ where dt is the length of computation interval in hour. If $SURF > E_p * dt$, the actual ET is $SURF + E_a * dt$. The maximum value of E_a is E_p.

If the contents of soil storage exceed a threshold denoted by FC, moisture flows out of it as interflow and recharge to groundwater. The excess moisture available for these two is :

$$Exw = (C_{soil}/C_{max} - FC) * Ewf \text{ if } C_{soil}/C_{max} > FC \tag{3}$$

where Ewf is a factor (mm/hr) controlling the volume of excess water. The volume of interflow is given as:

$$IntF = Exw * C_{int} \tag{4}$$

and the recharge to groundwater is

$$RECH = Exw * (1 - Cint) \tag{5}$$

where C_{int} is a dimensionless coefficient which governs the division of the excess moisture between recharge and interflow. The interflow is routed through a linear reservoir LR 2 with time constant K_i.

The groundwater zone behaves as a linear reservoir whose time constant is KG. The moisture comes out of it as the baseflow (BF). The flow coming out of the reservoirs LR 1, LR 2 and LR 3 is combined and then routed through a linear reservoir, LR 4, to yield the discharge from the catchment, denoted by TF. The box diagram of the model structure is given in Fig. 1.
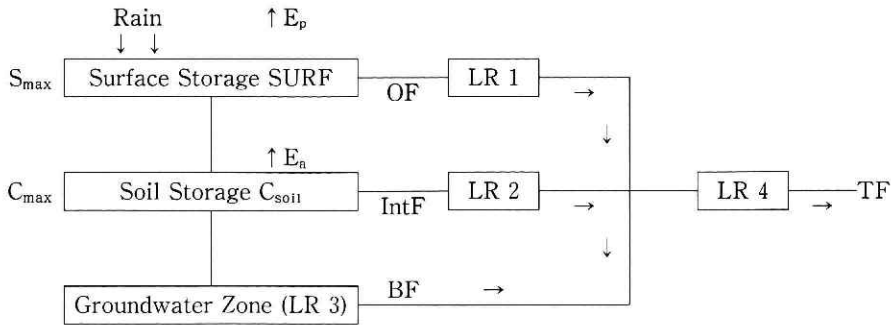
Fig. 1　Structure of the Model

The input to the model consists of the values of various model parameters, the period of simulation, and the time step size. The initial contents of various storages are also specified. The rainfall and potential evaporation data for the period of simulation are given as input. This model has been successfully used to simulate the response of a few basins.

3.　The study area and data used

The data of the Urajiro river experimental catchment of National Research Institute for Earth Science and Disaster Prevention (NIED). Japan, were used in this study. The Urajiro river is a tributary of the Yoro river. The catchment lies near the latitude 35° 18' and longitude 140° 08' in the Chiba prefecture. The catchment elevation varies from 284m to 55m and the areas of 0.15 sq. km. up to the Kakinokidai and 9.04 sp. km. up to the Tsukizaki gauge & discharge measurement sites were modeled. The Urajiro basin is in humid climate. the normal annual rainfall is 1820mm. In some years. the basin also experiences very small amount of snow which usually melts within a few hours. The soil is coarse, mostly volcanic ash type having large hydraulic conductivity. The index map of the basin is given in Fig. 2.

The daily rainfall data of the Kakinokidai station were used. The discharge (at Kakinokidai and Tsukizaki) are recorded using an analog chart-recorder and the values read at 10-minute interval were used to compute mean-hourly discharge. These values were used to obtain the daily and monthly discharges. The data for the period 1980-84 were used. For estimation of potential evaporation from the basins, the meteorological data at the Ushiko station were used. The hourly data for wind velocity sunshine-hours and air temperature were extracted from the Automatic Meteorological Data Acquisi-
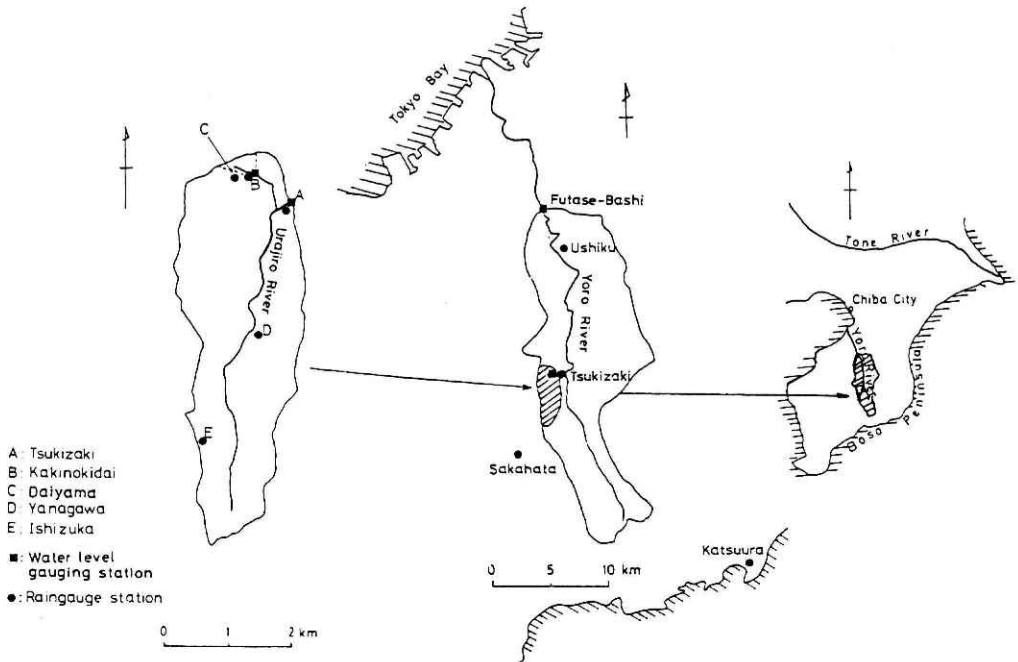
Fig. 2 Index map of the Urajiro experimentfal basin showing locations of rain and discharge measurement sites.

tion System (AMeDAS) database and the daily humidity data were taken from the Japan Meteorological Agency (JMA) publications. The procedure for Penman method, recommended by Dorrenbos and Pruitt (1977) was used to estimate PE. Since the Ushiko station is little away from the basin (13km), the estimation of PE may be somewhat unrepresentative.

4. Parameter estimation

The calibration process requires a procedure to evaluate a given calibration and then to further adjust the parameters if required The various aspects of calibration of a conceptual model have been discussed by Ibbit and O'Donnell (1973), Johnston and Pilgrim (1976), and Gupta and Sorooshian (1988). Several criteria are available in the literature to test the efficiency of a rainfall-runoff model, see Nash & Sutcliffe (1970) and Garrick et al (1978).

A two-stage process appears to work well for calibration of the model described above. The first stage involves matching the volumes of observed and simulated

hydrographs on monthly basis. In the second stage, the shape of the simulated hydrograph may be matched with the shape of the observed hydrograph. This approach gives a flexibility to the modeler to adjust the model parameters in light of the objectives of the study, e g., whether peak flow modelling is more important or low flow modelling.

Out of the ten parameters, four are time constants of various reservoirs which do not affect the volume of the simulated hydrograph (except the time constant of groundwater reservoir) and hence need not be calibrated in the first stage. Therefore, only six parameters, namely S_{max}, C_{max}, FC, F_{Inf}, C_{max}, and Ewf were determined. The Rosenbrock method, which is a search technique, was used for optimization. The objective function adopted was

$$\text{Min } Z = \sum (VO_t - VS_t)^2 \tag{6}$$

where,

VO_t = Volume of observed hydrograph in mm for month t,

VS_t = Volume of simulated hydrograph in mm for month t.

5. Results

The volumes of observed and simulated discharge hydrographs at Kakinokidai on monthly basis for the period Jan. 1980 to Nov. 1984 have been plotted in Fig. 3. The graph shows a reasonably good match between the observed and the computed hydrographs There appear to be some inconsistencies in the input data for a few months — the discharge coefficient (volume of discharge/volume of rainfall) was far greater than one. The rain gauging station whose data were used (Kakinokidai) is located in the lower altitude region and therefore the rainfall estimations may be on lower side. Moreover, for this catchment, the possibility of exchange of flow with the neighbouring areas in the subsurface zone cannot be ignored.

The plot of observed and simulated hydrographs for the Tsukizaki station for the period Jan. 1980 to Nov. 1984 is given in Fig. 4. A reasonably good match was also obtained for this station too. The catchment up to Kakinokidai is a hilly area while the major part of catchment up to Tsukizaki is relatively flat. It is also seen from the graph that the computed discharge peaks are generally on the higher side of the observed discharge up to 1982 while they are on the lower side subsequently. This might have been caused by some catchment change.
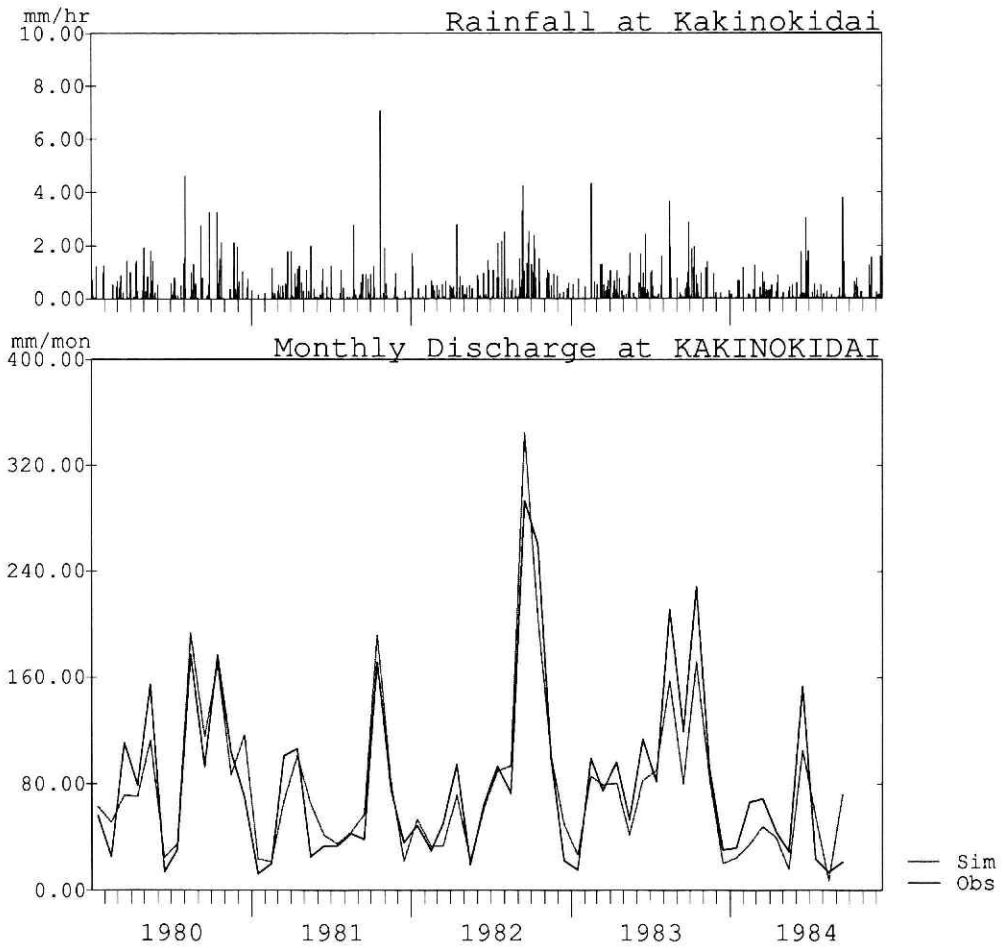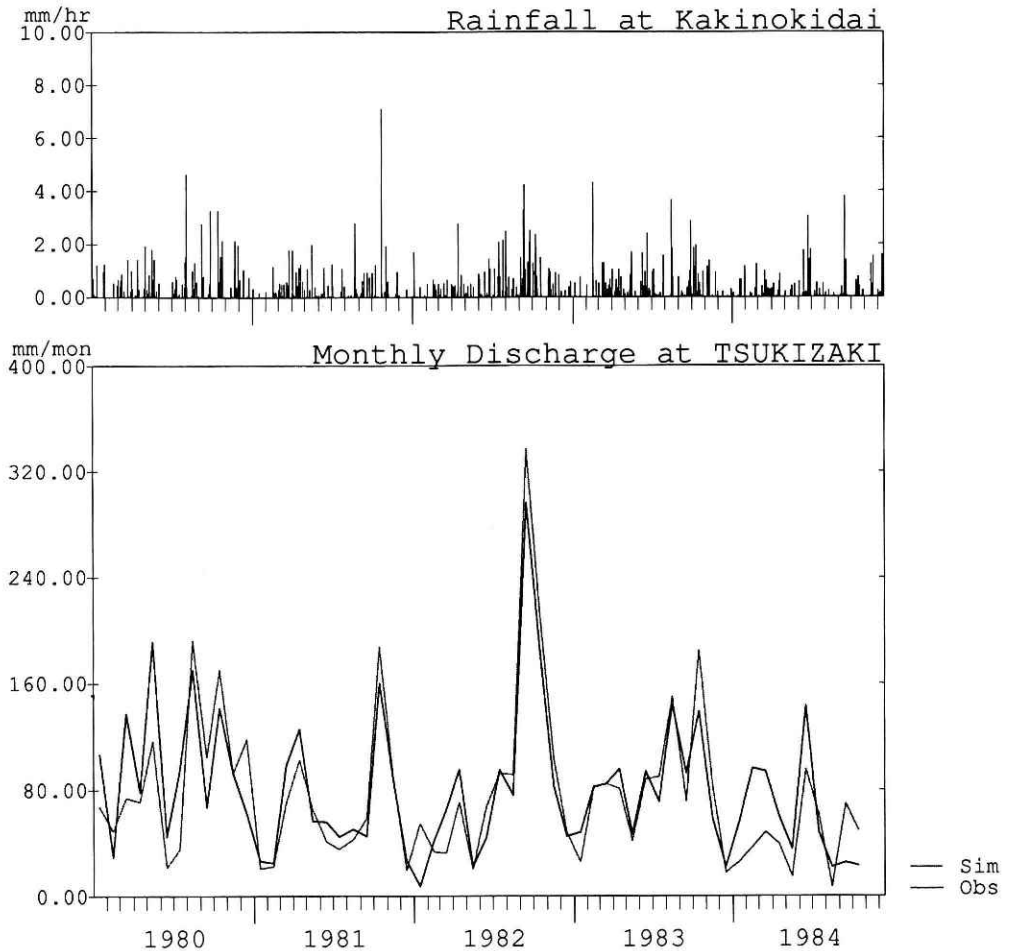
Fig. 3 Plot of observed and simulated hydrographs at the Kakinokidai station. The corresponding rainfall has been plotted in the upper graph.

Table 1 Optimum Model Parameters for the Catchments

Parameter	Up to Kakinokidai (Area 0.15 sp km)	Up to Tsukizaki (Area 9.04 sp km)
Smax	47.94	60.50
Cmax	42.00	38.75
FC	0.19	0.23
Finf	0.72	0.87
Cint	0.48	0.55
Fwf	0.81	0.88
CKG	400.00	400.00
Obj Fun.	35,978.	49.000.
Model Eff.	0.85	0.69

Fig. 4 Plot of observed and simulated hydrographs at the Tsukizaki station. The corresponding rainfall has been plotted in the upper graph.

Overall the results are acceptable. It may be mentioned that no attempt was made to match the shape of the hydrographs because short term data were not available. The values of the various model parameters for the two basins are given in Table. 1.

6. Conclusions

A simple conceptual model has been used to simulate the rainfall response of two small research catchments. The results are reasonably good for both the catchments.

7. Acknowledgemets

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