論　文

A Study of the Runoff Mechanism in the Mountainous Watershed

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山地流域における流出機構の研究

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要　旨　山地流域の出水特性は，従来から多くのモデルによって研究されている。著者らは，山地流域の出水特性が，山地斜面の流出機構に起因していると考え，山地斜面表層部の流出機構のモデルを提案している。このモデルは，"water-path"モデルと言い，山地表層部において，透水係数が上層から下層にかけて小さくなっていると考えた，流出機構のモデルである。そこで，このモデルの有効性を示すために，実際の出水データとのシミュレーションを行なった。その結果，実測データに良好に適合し，このモデルの有効性を示した。

Summary : It is generally considered that the characteristics of runoff are caused by the runoff mechanism in the mountainous surface layer. We made the hydrologic model of runoff in the surface layer. This model called "water-path"model represented that the hydraulic conductivity decreases downward in it. We carried out the simulation of the flood runoff events in order to test the application of the model. As the obtained results, the availability of "water-path"model was indicated by the simulation.

I　INTRODUCTION

In general, it is necessary to clarify the rainfall-runoff mechanism in order to design the flood control and the erosion control. However, it has not yet been clear hydrologically. The hydrologic models such as stochastic or kinematic wave model have described the characteristics of runoff, but these physical meanings were not clear. We made the runoff model called "water-path"model*(1,2)* which represented the runoff mechanism in the mountainous surface layer, and the physical meanings of its parameters were clear.

This paper analyzed the application of this model by the numerical simulation method using the storm flow events which were measured on IWAYAGOYA experimental watershed in Ehime University Forest. According to this simulation, the parameters of "water-path"model were determined and the application of the model for the flood hydrograph was examined.

As the results, the "water-path"model was provided more available for the runoff analysis in the mountainous watershed than the previous hydrologic model, because the parameters of this model were

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described physically.

II THE EXPERIMENTAL WATERSHED

The experimental watershed is situated in the KOMENONO Establishment of Ehime University Forest, the east of MATSUYAMA city in Ehime prefecture. This experimental watershed called IWAYAGOYA forest watershed (76.9ha) is shown in Fig. 1.

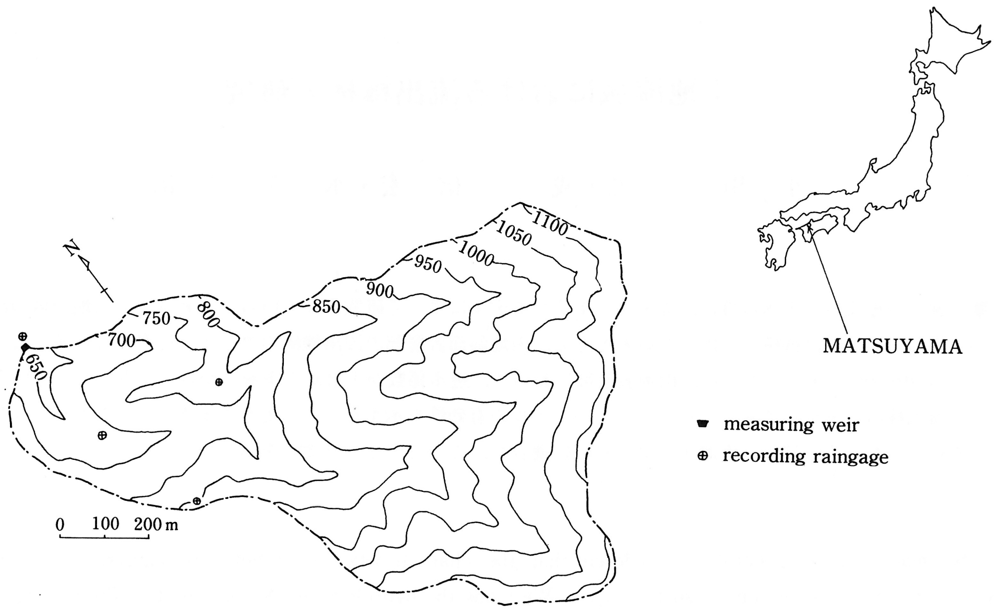

Fig. 1 IWAYAGOYA experimental watershed

It depends upon the four small catchments and is covered with the planted forests of sugi, Japanese cryptomeria (Cryptomeria japonica D. Don) and hinoki, Japanese cypress (chamaecyparis obtusa Sieb. et Zucc.), and the coppice forests of the broad leaves tree.

Precipitation was measured at four sites. The gage is a 0.5 mm tipping bucket rain gage recorded by a magnetic event recorder.

The stream-gaging weir is composed of the combination of a sharp-crested 120° V-notch weir with broad-crested weir.

The following equations were obtained as the stage-discharge curve in 120° V-notch weir,

$$Q = 2.822H^{2.5} \quad (1)$$

and in broad-crested weir,

$$Q = 7.128H^{1.5} \quad (2)$$

where, Q is discharge (m^3/sec) and H is water level (m) of weir.

The details of the stream-gaging station have been reported by OGAWA et al. *(3)*

III "WATER-PATH" MODEL

The "water-path"model is the improved model of the kinematic wave model. In this model, it is considered that the rainfall occurs the infiltration in gravitational direction and the inter flow in the surface layer, because the hydraulic conductivity is not constant in the surface layer and decreases downward in it. The inter flow in slope direction is called the flow of "water-path". The "waterpath" model physically represents this flow.

It can be mathematically expressed by the equations. Firstly, the flow of "water-path" is considered as inter flow, so that the flow velocity V_* is given by Darcy's equation as follows :

$$V_* = k_0 \sin\theta \qquad (3)$$

where, V_* is effective velocity of flow, and k_0 is effective hydraulic conductivity. As the hydraulic conductivity should be varied with the depth of flow, k_0 is considered as a function of h_* as follows :

$$k_0 = \beta\, h_*^{n} \qquad (4)$$

where, h_* is effective depth of flow, β is a constant, and n is an exponential constant. Assuming the cross-section of "water-path" as rectangular, the effective width b_* of "water-path" is expressed as $\alpha' h_*$:

$$b_* = \alpha' h_* \qquad (5)$$

It is considered that α' varies in longitudinal direction, so that it is presumed as a function of h_* :

$$\alpha' = \alpha\, h_*^{m} \qquad (6)$$

where, α is a constant, and m is an exponential constant.

Therefore, the cross-sectional area of "water-path", A_*, is written as :

$$A_* = b_* h_* = \alpha\, h_*^{m+2} \qquad (7)$$

Using Eq. (3) and Eq. (7), the kinematic-momentum equation is given :

$$A_* = K Q^{P} \qquad (8)$$

$$K = \alpha\,(1/\alpha\,\beta \sin\theta)^{P}$$

$$P = (m+2)\,/\,(m+n+2)$$

where, Q is discharge, and the continuity equation is :

$$\frac{\partial A_*}{\partial t} + \frac{\partial Q}{\partial x} = r_e \cos\theta\, U_l \qquad (9)$$

where, U_l is unit width of slope on which a "water-path" is formed, r_e is effective rainfall, θ is gradient, t is time coordinate, and x is space coordinate.

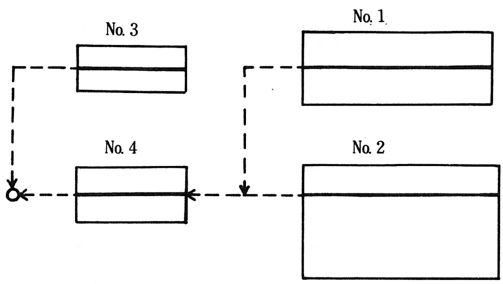

Fig. 2 Geometrical representaion of the experimental watershed

Ⅳ REPRESENTATION OF THE EXPERIMENTAL WATERSHED

In order to carry out the runoff analysis, the IWAYAGOYA watershed is divided into four rectanguler catchments as in Fig. 2. According to the practical method of the geometrical simplification of catchment, the length of channel where water is always flowing is determined, so that a width of slope plane is obtained from the relationship of the catchment area. The gradients of channel and slope plane also obtained by measuring of the map on a scale of 1/5000. These parameter values of the simplified rectangular catchments are shown as in Table 1.

Table 1 Parameter values of the rectangular catchment

Parameter	Catchment No. 1	No. 2	No. 3	No. 4
Catchment area (ha)	23.0	35.7	7.0	11.2
channel length of projection (m)	858	880	476	580
Channel gradient ($\sin \theta_c$)	0.328	0.333	0.308	0.164
Slope length of projection (m)	134	113 291	73	96
Slope gradient ($\sin \theta$)	0.595 0.588	0.620 0.588	0.586	0.521
Channel length (m)	908	933	500	588
Channel width (m)	1	1	1	1
Slope length (m)	166 165	144 360	90	113

V THE NUMERICAL CALCULATION OF THE RUNOFF

The effective rainfall was estimated by means of the relationship between the sum of rainfall and the sum of rainfall loss that were computed from the eleven storm flow events as in Fig. 3. It is considered

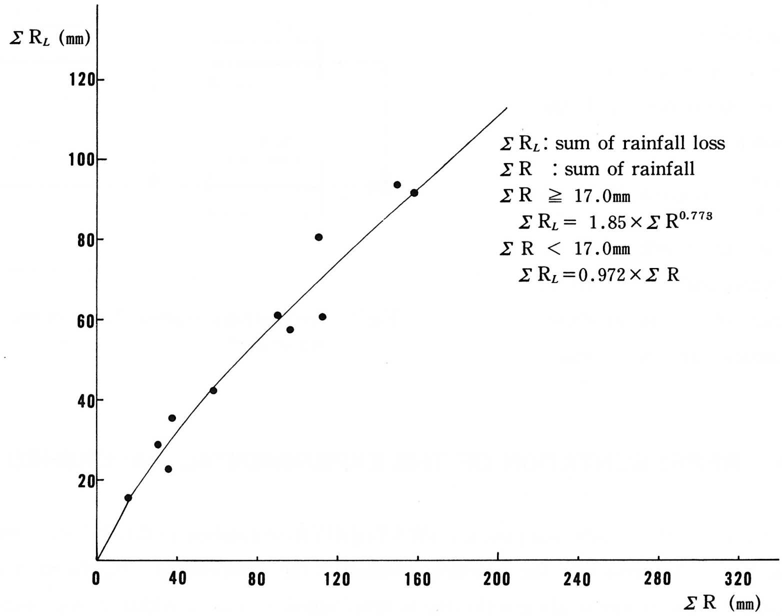

Fig. 3 Sum of rainfall and sum of rainfall loss

that the flow of channel is overland flow and the resistance parameter of overland flow is given by the value of Manning's roughness coefficient N.

The value of N is given as $N = 0.075$ $(m^{-\frac{1}{3}} \cdot s)$ in a natural mountainous channel. The cross-section of channel is assumed as a rectanguler of one meter width.

Therefore, using Manning's equation, the kinematic-momentum equation for the channel section can be written as :

$$A = K Q^P \qquad (10)$$

$$K = (N / \sqrt{\sin\theta_c})^P$$

$$p = 0.6$$

where, A is cross-sectional area, and θ_c is channel gradient.

In the next place, the constant m is given m = 1, because the cross-section of "water-path" is assumed as rectangular and the constant α is given α = 13, so that the effective width may accord with one-third of a unit slope width. This simulations to the observed hydrographs have been done by varying the values of β and n.

In the kinematic wave method, the characteristic curves generally start from the upstream at the interval time of the differential time Δt. The discharges and the concentration times were computed at the end of slope. In this method, the discharge of the end of slope can not be ordinary obtained at equal interval time as shown in Fig. 4 (A). Varying the differential time Δt to $\Delta t'$ in this paper, we make the characteristic curves arrive at the end of slope as required time in Fig. 4 (B).

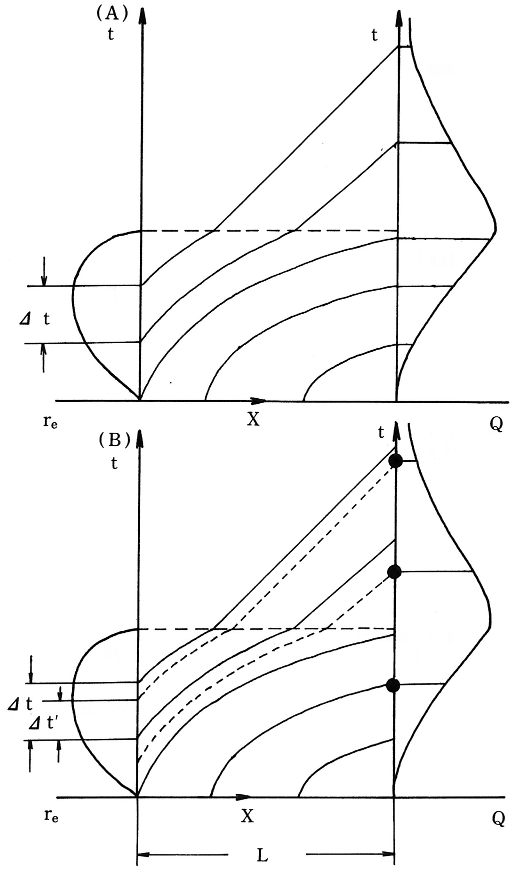

Fig. 4 Diagram of characteristic curves for kinemematic wave
r_e: effective rainfall Q : discharge L : slope length
$\Delta t, \Delta t'$: differential time ● : reguired time

Therefore, the interval time of computed discharge can be made to equal, and it is useful when the channel and next catchment discharge are computed. However, the running of this computer program takes much time.

Ⅵ RESULTS AND DISCUSSION

The results of the simulation applied the "water-path"model are shown in Fig. 5,6. These observed hydrographs were middle flood events in the watershed. According to the trial computation, β and n of this model were obtained as shown in Table 2.

We obtained satisfactory agreement between the observed and the computed hydrograph. From the results described above, the "water-path"model represented physically is available for the runoff analysis in the mountainous watershed.

Strictly speaking, however, the rising hydrograph dose not just fit. It seems that it is caused by the input pattern. Therefore, it is important how to estimated the effective rainfall.

We are indebted to the staffs of the KOMENONO Establishment of University Forest for providing the data for us.

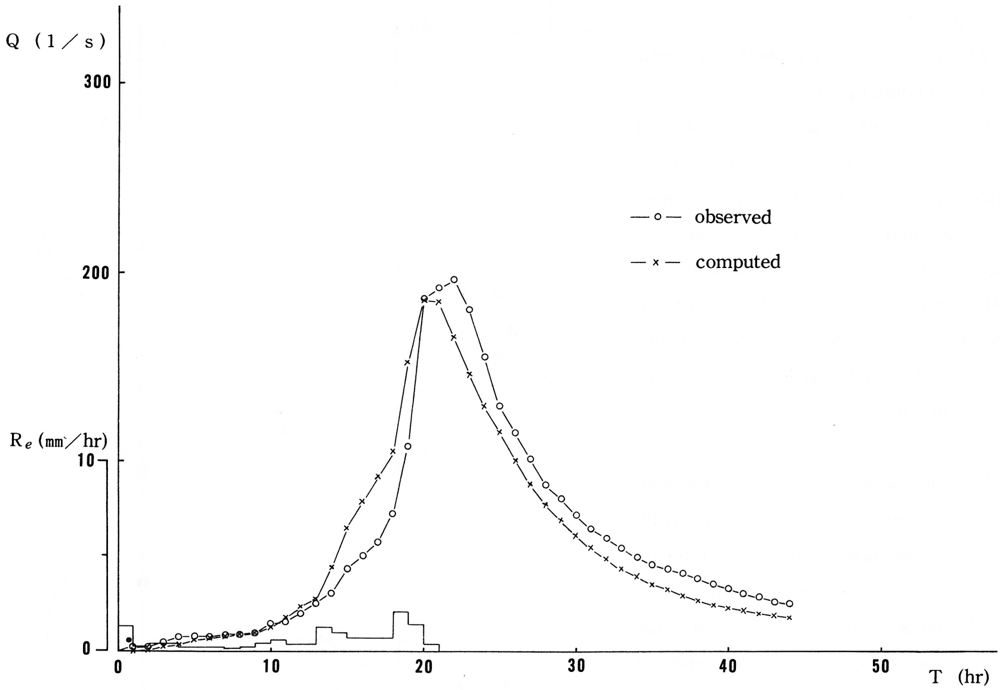

Fig. 5 Observed and computed hydrographs

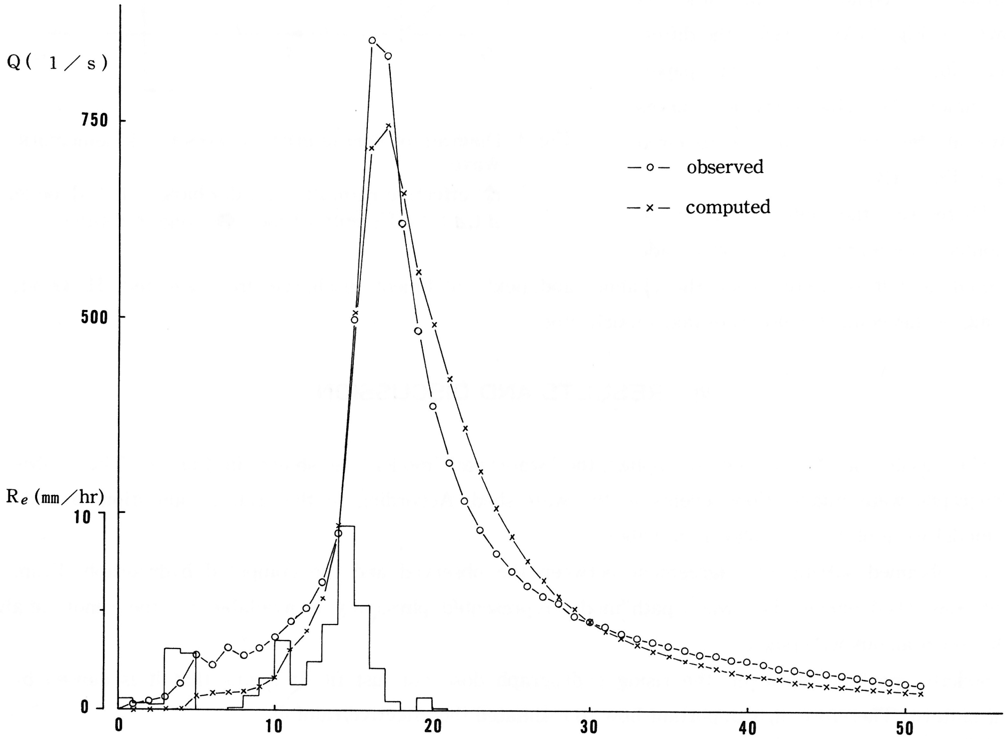

Fig. 6 Observed and computed hydrographs

Table 2 Parameter values in the "water-path" model

DATE	β	n	α	m	
1979. 11.9	45.0	3.7	13.0	1.0	Fig. 5.
1980. 5.15	15.0	3.7	13.0	1.0	Fig. 6.

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* in Japanese with English summary

**in Japanese

(Received August 30. 1980)