Modeling a Physical-based Watershed Hydrologic Response Function through Applying Land Use, DEMs and Time-Area Diagram

Department of Civil Eng., Kyoto Univ. Student Member of JSCE, ○Shen CHIANG
Disaster Prevention Research Institute, Kyoto Univ. M.JSCE, Yasuto TACHIKAWA
Disaster Prevention Research Institute, Kyoto Univ. M.JSCE, Toshiharu KOJIMA
Disaster Prevention Research Institute, Kyoto Univ. F.JSCE, Kaoru TAKARA

1. Introduction

The central idea of the time-area method is a time contour or an isochrone. An isochrone is a contour joining those grid cells in the watershed that are separated from the outlet by the same travel time. Hence, the time-area diagram indicates the distribution of travel times of different parts of the watershed drains to the outlet[1]. Through describing the water movement mechanism by kinematic wave routing method, the time consuming of a raindrop fallen down to any specific site till it drains to the outlet can be calculated. Exploring the relationship of the travel time and the number of grid cells (i.e. time-area diagram), a histogram can be extracted. Comparing the procedure described above to the concept of instantaneous unit hydrograph, it is clear that they are equivalents. Which implies a physically based watershed response function can be extracted in this way.

In this study, a distributed instantaneous unit hydrograph is established and applied in the Yasu River basin(377km^2). The distributed instantaneous unit hydrograph proposed herein reflects topographic feature(e.g.: land cover, slope, etc.) of the basin in hydrologic response function, also consider the water movement scheme which caused by the rainfall processes.

2. The derivation of the distributed instantaneous unit hydrograph of the basin

Concept of the instantaneous unit hydrograph has been revealed by Clark[2] in 1945. In this study, derivation of the distributed instantaneous unit hydrograph could be divided into several steps as below:

(1) Usage of DEM

Comparing the elevation of the central grid to its eight adjacent cells, the flow direction of the central grid could be determined. According to the flow direction, the flow path from specific grid to the outlet of the basin and the drainage area of the grid can be retrieved; the distance of each grid inside the basin to the outlet is calculated according to the length of the flow path.

The distance-area curve obtained hereinbefore is simply space related; no temporal relationship is included. To obtain the temporal relationship kinematic wave routing method is used, in this study, to transfer the distance into time. For this purpose, land use data for determining the roughness coefficient and rainfall data for outflow calculation is necessary.

a) Landuse data

The roughness coefficient was determined from the land use data in 1977 acquired through the web page of Ministry of Land, infrastructure and transport, as shown in **Fig.1**. **Table 1** shows the category of the land use and its percentage inside the basin. The value of the Manning roughness coefficient was calibrated by several rainfall events.

Fig.1 Land use of Yasu River basin.

Categories	Percentage
Paddy field	19.39%
Agricultural usage	2.41%
Other usage	3.36%
River and lake	4.47%
Forest	59.70%
Wasteland	2.01%
Artificial building	6.38%
Traffic usage	0.36%
Golf field	1.92%

Table.1 Category of land use and its percentage.

b) Rainfall data

The rainfall data was collected from four rainfall gauging stations inside the Yasu River basin, they are Yasu, Minakuti, Kouga and Oogawara, as shown in **Fig.2**. The average precipitation was calculated according to the weight of each rainfall station which obtained by using Thiessen polygon method.

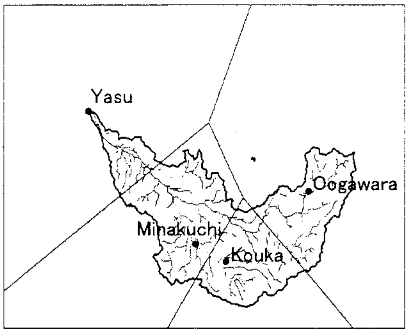

Fig.2 Locations of the rainfall stations and Thiessen polygon.

(2) Extraction of instantaneous unit hydrograph

The distance of each cell to the outlet of the basin according to the flow path could be easily obtained by utilizing DEMs; by comparing the level of adjacent grid cells around the specific one, flow direction could be determined; the drainage area of specific area can be calculated by counting the number of cells which drains into the specific cell according to the flow direction. With given roughness coefficient value and rainfall intensity, it is possible to calculate the water depth of specific location by Eq. (1) as below:

$$y = \left(\frac{n}{\sqrt{s}}\frac{i_e \cdot DA}{B}\right)^{\frac{1}{m}} \tag{1}$$

where y denotes water depth, n denotes Manning roughness coefficient, s denotes slope, i_e denotes the effective rainfall, DA denotes drainage area, B denotes cell width and m is 1.67.

The flow velocity then can be calculated by Eq. (2) as below:

$$V = \frac{n}{\sqrt{s}} y^{m-1} \tag{2}$$

where V denotes the flow velocity; the travel time which raindrop drains from point to next point can be calculated by divides the distance between two points by the flow velocity V.

Consequently, the time-area diagram which equals to the watershed instantaneous unit hydrograph can be extracted as shown in Fig. 3.

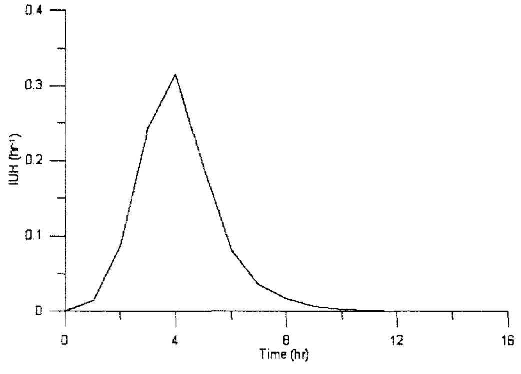

Fig.3 Instantaneous Unit hydrograph of Yasu River Basin.

3. Result and conclusion

In this study, 2 storm events of Yasu river basin were simulated as shown in Fig. 4 and 5. For the event of 19th to 22nd June, 1997, the error of peak discharge is -2.45%, and the error of time to peak is 1 hour. As for the event of 18th September to 2nd October, 1998, the error of peak discharge is -4.56%, the error of time to peak is 3 hour. Which implies that the IUH derived from FAV shows better fit for short period rainfall-runoff simulation.

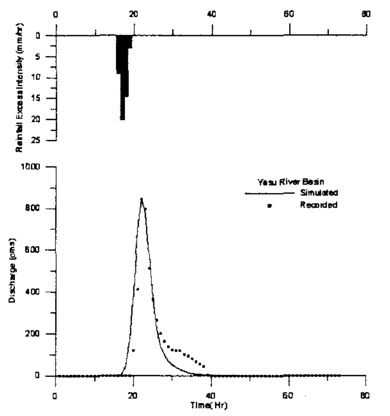

Fig.4 (1997/06/19.17-06/22.02)

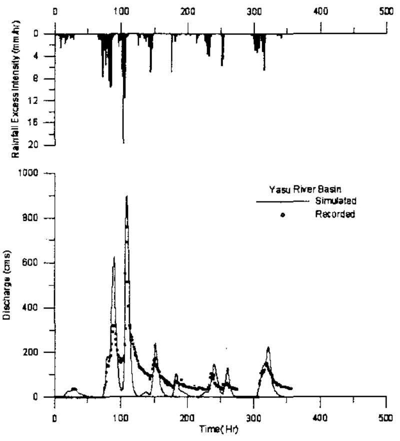

Fig.5 (1998/09/18.08-10/02.12,)

Manipulating UH to estimate the stream flow hydrograph of the specific point need lots of hydrologic record, for ungauged area and those basin which the hydrologic environment changed by human activity or urbanization, it is inadequate to adopt the method. A geomorphologic instantaneous unit hydrograph could solve such problem.

Compare to the traditional geomorphic hydrologic model, the distributed IUH was acquired by the DEM, there is no need to acquire the geomorphic factors, if the model connected to the Remote Sensing data in the further study, the simulation of the ungauged area will be more accurate. As for ungauged area or lacking of hydrologic record zone, the geomorphologic IUH proposed herein is expected to be a convenient way for water resources designing.

4. Reference

1) Singh, V. P.: HYDROLOGIC SYSTEMS Rainfall-Runoff Modeling, Vol. 1, Prentice Hall, 1988.

2) Clark, C. O.: Storage and the unit hydrograph, *Tran. ASCE*, Vol.110, No.2261, pp.1419-1446, 1945.