第Ⅱ部門 **Lumping of Physically Based Distributed Rainfall-Sediment-Runoff Model Considering Spatial Distribution of Topographic Variables and Overland Flow Transport Capacity**

DPRI, Kyoto University, Student Member ○ APIP
DPRI, Kyoto University, Member Takahiro SAYAMA
DPRI, Kyoto University, Member Yasuto TACHIKAWA
DPRI, Kyoto University, Fellow Kaoru TAKARA

1. Introduction

Estimates of total runoff and sediment yield in catchment scale are required for solution of a number of problems. Design of dams and reservoirs, design of soil conservation, land-use planning, and water quality management are some of the examples. Researches have shown that the annual sediment yield was correlated highly with sediment transported during the flood events. Therefore a heavy rainfall event-based sediment-runoff estimation approach is necessary to dynamic modelling of runoff and sediment yield. These interactions can be represented within complex physically-based distributed models. But, physically-based distributed models usually work at a small size and require a large amount of data and lengthy computation times. Liu and Todini (2002) developed a comprehensive distributed-lumped approach allows for the extensive simulations needed when used in combination with a stochastic rainfall generator for deriving, and continuous simulation. Theoritically it proves that the lumped version can be derived directly from the results of the distributed version.

The lumped model derived from the kinematic wave equation considering spatial distribution of topographic information and water content of slope systems has developed to simulate runoff processes and to reduce computational burden required in a long-term runoff simulation (Ichikawa and Shiiba, 2002). The primary objective of this study was to lump a physically based distributed rainfall-sediment-runoff model, we have been adopted and extended the lumping method which used in that model to include sediment transport processes which can be solved analytically and to explore how sediment yield is related to hydrological response, erosion source and depositional processes. The main advantage of this approach lies in it capability of being applied at increasing spatio-temporal scales without losing model and parameter physical interpretation.

A Physically Based Distributed Rainfall-Sediment-Runoff Model

A physically based distributed rainfall-sediment-runoff model deriving from the integration in space of the kinematic wave model was developed by authors. The concept of sediment transport algorithm considering the sediment movement on a catchment scale by combining erosion, deposition, and transportation processes with the grid-cell based Kinematic Wave Runoff (KWR) model. The concept of spatially distributed modeling is shown in Figure 1.

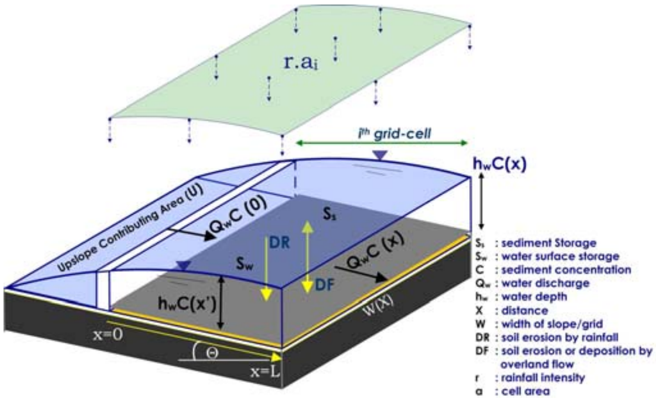

Figure 1. Schematic of the physically based rainfall-sediment-runoff variables at grid-cell scale.

The simulation area is divided into an orthogonal matrix of square cells, assumed to represent homogenous conditions; runoff generation (Q_w) and soil erosion-deposition (net erosion) are computed for each grid-cell. The net

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erosion is calculated by adding *DR+DF*. From observation of rainfall characteristic in our study area (**Lesti river-Indonesia**), the empirical equation for *DR* (kg/h) expressed as a linear function :

$$DR_i = 56.48\, r_i a_i$$

DF (kg/h) is simulated as a result of Q_w, following the sediment Transport Capacity of water (*TC*): if *C<TC* erosion occurs, otherwise excess soil deposition (Govers, 1990). The equation is :

$$DF_i = \alpha (TC_i - C_i)\, h_i a_i \rightarrow (\alpha = 0.98)$$

Simulation result by distributed model :

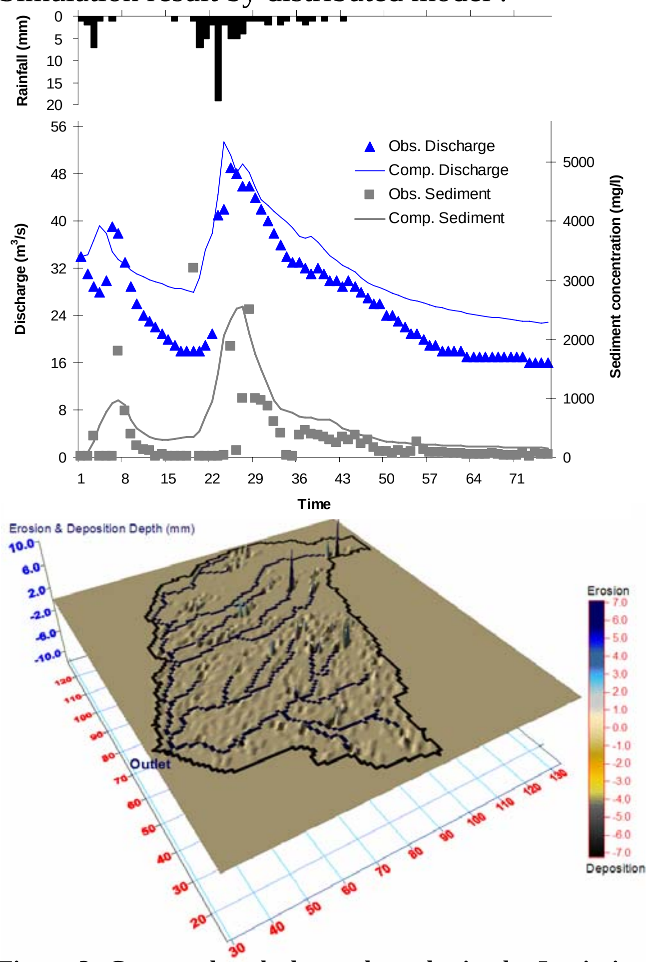

Figure 2. Computed and observed results in the Lesti river (October 3-6, 2003) : (a) hydrograph and sedimengraph (b) 3-D spatial distribution map of erosion and deposition sources.

Lumping of The Distributed Model

Based on the assumption of steady state conditions of rainfall-runoff, the relationship between total storage of water in the i^{th} grid-cell (S_{wi}) and the discharge flow the i^{th} grid-cell (Q_{wi}) can be theoretically derived. Flux of Q_{wi} is expressed as the product of *r* and *U*. *U* can be calculated from a DEM from each grid-cell. The storage of water in catchment scale ($\bar{S}_w$) can be calculated by adding up the S_{wi} from each grid-cell as a function of the topographic variables. Furthermore, sediment transport scheme have been included. *TC* is function of topographic variables and hydrological responses in each cell-grid. *C* is assumed to be uniform over the catchment and this is the variable of sediment continuity. The maximum sediment storage of the catchment (S_s^{max}) can be calculated from each grid-cell based on S_{wi} and TC_i which are mathematically derived from $\bar{S}_w$. Finally, the continuity equations of $\bar{S}_w$ and $\bar{S}_s$ on a catchment scale are presented as follows :

$$\frac{d\bar{S}_w}{dt} = rA - \bar{Q}_w \quad \text{where } \bar{S}_w = K\left(\bar{Q}_w\right)^p$$

$$\frac{d\bar{S}_s}{dt} = DR + DF - \bar{Q}_w C(1-e_v) \text{ , } C = \frac{\bar{S}_s}{\bar{S}_w}$$

$$= 56.48\, r + 0.98\left(S_s^{max} - C\bar{S}_w\right) - \frac{\bar{Q}_w \bar{S}_s}{\bar{S}_w}(1-e_v)$$

Basic equations :

$$h(x,t) = \left(\alpha^{-1} r\left(\frac{U}{w} + x\right)\right)^{1/m}, p = 1/m, \alpha^{-1} = \left(\frac{n}{\sqrt{\sin\theta}}\right)^p = k$$

$$S_{wi} = \int_0^L A(x,t)dx = w\int_0^L h(x,t)\, dx$$

$$\bar{S}_w = \sum_{i=1}^{z} S_{wi} = r^p \sum_{i=1}^{z} \frac{wk}{(p+1)}\left(\left(L + \frac{U}{w}\right)^{p+1} - \left(\frac{U}{w}\right)^{p+1}\right)$$

$$= \left(\frac{\bar{Q}_w}{A}\right)^p \sum_{i=1}^{z} \frac{wk}{(p+1)}\left(\left(L + \frac{U}{w}\right)^{p+1} - \left(\frac{U}{w}\right)^{p+1}\right)$$

$$= K\left(\bar{Q}_w\right)^p$$

In which *A*: catchment area, e_v: trapping efficiency by land cover, *m*: constant, *i*: index of a grid-cell, and *z*: total of grid-cell, *n* : roughness coefficient, *L*: slope length, *t*: time and $\bar{Q}_w$: outlet discharge.

The model is foreseen to be suitable for large catchments, land-use and climate change impact assessment, for extreme flood analysis, for use with Genaral Circulation Models (GCMs).

References

Ichikawa, Y. & Shiiba, M. 2002. Lumping of Kinematic Wave Equation Considering Field Capacity. Third International Conference on Water Resources and Environmental Research. 22nd-25th of July 2002 at Dresden University of Technology.

Liu, Z. & Todini, E. 2002. Towards a Comprehensive Physically-Based Rainfall-Runoff Model. Hydrology and Earth System Sciences, 6(5), 859-881.