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A GIS Based Distributed Catchment Model for the Simulation of Urban Hydrology

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Introduction

With the growing realization of the necessity of integrated water management in urban areas, there is a need to develop catchment hydrologic models which incorporate not only the spatial heterogeneity of the catchment, but also the components of natural and artificial (human water usage) water cycle. Geographic Information Systems (GIS) is an indispensable tool for not only the preparation of the input data for such simulations, but also for utilization of simulation results for water management planning. The present paper discusses such a model, and its application to an urban catchment.

Model Description

The model is a grid based numerical simulation model, developed as an extension of a GIS system, which simulate different hydrological processes and their interactions. In the GIS, catchment topography, landuse, soil distribution, population distribution, drainage network and catchment geology are treated as permanent maps. Rainfall, atmospheric data for the computation of potential evaporation and water supply are treated as transient maps, which are updated regularly using measured data. Then the water movement represented by, surface flow, subsurface flow, infiltration, ground water flow, river flow, house hold water discharge, etc., are computed using governing equations, and are represented as resultant maps. These maps can be stored at prescribed intervals.

Governing equations

The descretization in the vertical direction and the interaction between adjoining grids are shown in fig. 1. In the numerical model, water pressure is used as the independent variable.

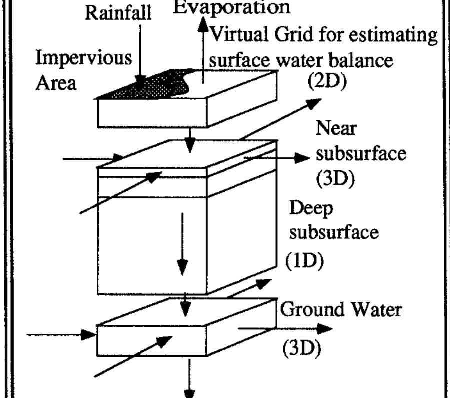

Fig.1 Vertical descritization of a grid column

Natural water Cycle

The topmost virtual grid is used for water balance computation. Rainfall input, evaporation and infiltration capacity obtained by solving infiltration equation for subsurface, are used in the water balance computations. The direct runoff component is then estimated as, $Df = Pex + S^{n-1} - S_{\max}$ where $S_{\max}$ is depression storage of the grid. This water balance is solved separately for pervious and impervious areas.

The upper sub surface is represented by two layers. In each grid in these layers, Richards' equation given below is used to simulate the subsurface flow

$$c(\varphi)\frac{\partial\varphi}{\partial t} = \frac{\partial}{\partial x}\left[k(\varphi)\frac{\partial\varphi}{\partial x}\right] + \frac{\partial}{\partial y}\left[k(\varphi)\frac{\partial\varphi}{\partial y}\right] + \frac{\partial}{\partial z}\left[k(\varphi)\frac{\partial\varphi}{\partial z} + k(\varphi)\right]$$

The infiltration from the upper subsurface to the groundwater is represented by a one dimensional Richards' equation, directly applied between the ground water and the upper sub-surface. The ground water flow is simulated using the 3D form of governing equation considering leakage to deeper aquifers. The discharge to river from the aquifer is obtained by applying Darcy's law between the groundwater table and the river.

Artificial Water Cycle

Water supply at each grid is estimated by population distribution and water supply data. The continuity equation at each grid is taken as,

AW discharge = AW in - AW leakage - AW loss

AW leakage = AW in x lc
AW loss = (AW in - AW leak) lf
AW in = C x I x p

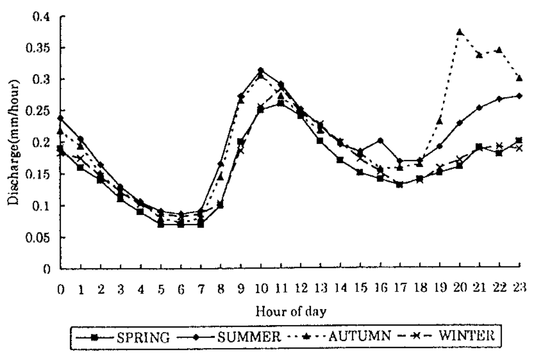

Fig. 2 Observed daily artificial discharge pattern

where *AW* represent Artificial Water. *lc* is the leakage coefficient, and *lf* is the loss factor, which can be estimated from observed data. Leakage represent water loss from transport lines which is taken as an input in the subsurface zone. Loss is the amount of water consumption. The parameter I represent the daily water supply/person and *p*, the population distribution within the grid. C is a conversion factor used in converting water supply records.
The diurnal pattern of the discharge is determined from observations as shown in fig. 2. Hourly discharge is then represented as, D(t) = AW dis x F(t), where F(t) is the unit discharge pattern function.

Model Application

The above described model was applied to Myhara sub catchment with an extent of 3.25 sq. km of Ebi river basin located in Chiba prefecture, Japan. The landuse were determined from 20m SPOT data, and DEM was developed using 50 m resolution numerical elevation data of Japan Geophysical Survey Institute. Water consumption was estimated as 304 l/day/person. Soil parameters were estimated from field tests and laboratory tests. Population distribution in each grid was carried out according to landuse. Fig. 3, shows a sample of simulated and observed river discharge at the catchment outlet. In addition to time series data, the model provides spatial distribution of hydrologic variables.

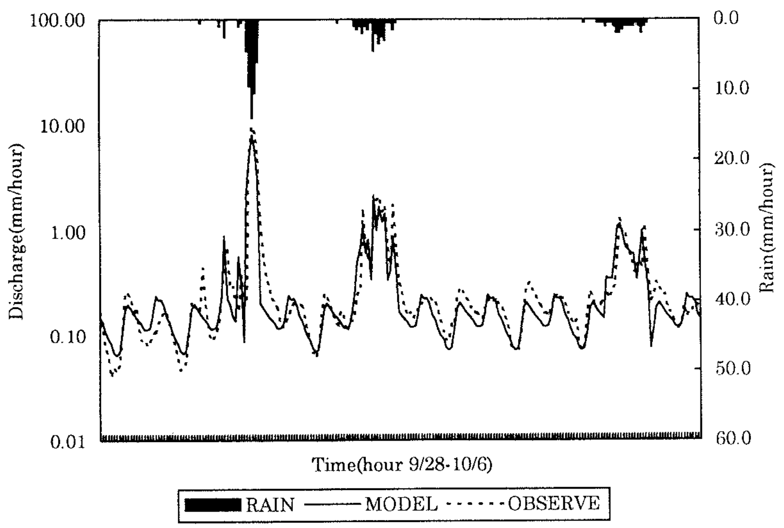

Fig. 3 Comparison of observed and computed river discharge

Conclusions

Modeling of catchment hydrology as a coupled system with GIS has made data input and result utilization easy. The model computations agree very well with the observations, indicating that the simplification adopted in the subsurface zone is justifiable. The model described here provides the output in the form of maps which can be easily integrated with catchment characteristic maps for water management purposes.

References

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