II − 3 THE INTERACTION BETWEEN EVAPOTRANSPIRATION AND SOIL MOISTURE

○NOURBAEVA Gouldaria, TOHOKU University, Civil Engineering Department, School of Engineering
KAZAMA So, TOHOKU University, Civil Engineering Department, School of Engineering
SAWAMOTO Masaki, TOHOKU University, Civil Engineering Department, School of Engineering

1. INTRODUCTION

Interaction between soil moisture content and evapotranspiration rate exhibits a high degree of theirs temporal variability. Along with soil heterogeneity and topographic characteristics, there are two important processes controlling their interaction. First, in soil column, soil moisture affected by water table fluctuation. Second, solar radiation and other atmospheric characteristics influence on evapotranspiration rate by drying of available water from soil. Soil water and evapotranspiration influenced by groundwater and atmospheric conditions make difficult to estimate the catchment components of water budget in hydrological problems. Therefore, consideration of both water and energy fluxes are necessary. The extension of Priestley-Taylor equation for evapotranspiration, proposed by Davies and Allen[1] is coupled with water balance approach. Cycling iteration of coupled model at fixed time brings to steady values of soil moisture and evapotranspiration.

2. DATA

The study area is the 970 km^2 Natori river basin, which is located between 140°6'E-141°10'E and 38°5'N-38°8'N, in Miyagi prefecture, Japan (Fig.1). Japan. The meteorological data are obtained from three observation stations within a watershed on an hourly frequency from the AMeDAS database. The meteorological variables include rainfall, air temperature and sunshine duration. Groundwater level data and discharge data are obtained from the Tohoku Regional Bureau Ministry of Land, Infrastructure and Transport. Groundwater level data for year 1992 at four observation points within the Natori River catchment are the time series with daily frequency. Data is collected in 1992.

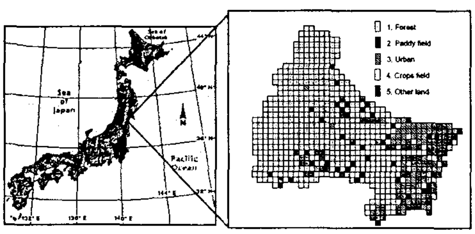

Figure 1 Study area and landuse map of study area.

3. METHODOLOGY

3-1 Soil-Water Interaction Model

Bierkens[2] proposed the model of soil-water interaction based on the water balance scheme. Assuming the equilibrium soil moisture condition, the snow effect was not considered in this model. Simple balance equations describing the soil-water and groundwater system are given by:

$$dh = \left[\frac{P(t) - AE(h,t) + q_v(t) - q_d(t)}{G(h)}\right]dt \qquad (1)$$

where $h(t)$ is the height of the water table at time t with respect to sea level, $P(t)$ is precipitation rate at time t. $AE(h,t)$ is actual evapotranspiration at time t, estimated from air temperature using the Hamon equation[3].

The expression for deriving a dynamic storage coefficient is given by:

$$G(h) = \varepsilon_0 + (\theta_s - \theta_r)(1 - \{1 + [\alpha \cdot (z-h)]^n\}^{-\frac{n+1}{n}}) \qquad (2)$$

where z is the elevation of the ground surface. The Van Genuchten parameters α and n depend on the soil characteristics and can be defined from a standard retention curve and look-up tables, proposed by Wosten and Van Genuchten[4]. The regional flux at time t to/from deeper groundwater (positive direction is upward) is $q_v(t)$. The contribution to the surface water at time t in mm equivalent is $q_d(t)$. Here $q_d(t)$ is derived by Darcy's law with the surface saturated hydraulic conductivity determined from the soil texture information.

The spatial distribution of water table depth is estimated taking into account the topographic index, calculated as a function of contributing area and slope at location. Using elevation map of catchment the topographic index, I_x, can be calculated for each cell by the following formula (Quinn et al. [5]):

$$I_x = \ln\left(\frac{u}{\tan\beta}\right) \qquad (3)$$

where u is the upslope area, per unit contour length, contributing flow to the location. In this case, the study unit area has size 1×1 km. The local slope between current cell and downstream cell in flow direction $\tan\beta$.

The water table depth, wd, can be spatially extrapolated from measured values at fixed time using following equation:

$$wd = \overline{wd} - \frac{1}{f}\{I_x - \overline{I}_x - \ln(K_0/f) + \overline{\gamma}\} \quad (4)$$

where f is the parameter, controlling the rate of decline for transmissivity, assumed to be constant in space, K_0 is surface saturated conductivity and $\overline{wd}$ is average depth to the water table in a catchment. Here $\overline{I}_x$ and $\overline{\gamma}$ are the averaged catchment values of topographic index I_x and parameter $\ln(K_0/f)$, respectively.

3-2 Parameterization of Regional Evapotranspiration from Nonsaturated Surfaces

The nonlinear relationship between actual and potential evapotranspiration for vegetated surface has been investigated in number of studies (Davies and Allen[1], Barton[6]. $\lambda AE/\lambda PE$ has an empirical logarithm function and evaporation from a non-saturated vegetated surface can be presented by the Priestley-Taylor equation can be as follow:

$$\lambda E = 1.26[1 - \exp(-10.563 \cdot S)]\left[(R_n - G) \cdot \frac{\Delta}{\Delta + \gamma}\right] \quad (5)$$

The parameters of Equation (5) are obtained from satellite data[2].

4. RESULTS AND DISCUSSIONS

At first, using the water balance approach, described by Equation (1), the distribution of water table depth in a catchment is estimated. The results were validated in subcatchment area with discharge data. The comparison between results of two approaches shows good agreement (Fig.2).

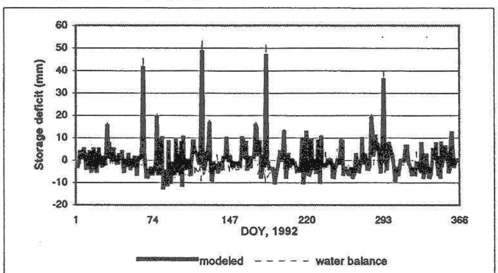

Figure 2 Comparison between modeled storage deficit values and predicted storage deficit values from general water balance equation.

The model steps are follows: at the beginning the soil moisture calculated by Equation (1) of soil moisture model, using the evapotraspiration values, calculated from Hamon equation. After that, derived soil moisture map is inputted to Equation (5) to obtain updated evapotranspiration value. That ET value is inputted to the Equation (1) to calculate updates for soil moisture. Cycling iteration of coupled model at fixed time brings to steady values of soil moisture and evapotranspiration. The resulting maps for steady evapotraspiration are

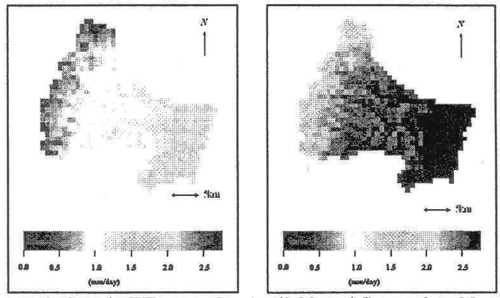

Figure 3. Steady ET maps for April 20 and September 22, 1992.

shown in Figure 3. The lowland area characterized by high values of evapotranspiration than upper mountainous area. The reason is that vegetation height in lower area is small and soil is much effected by atmospheric condition. Also, the lowland area has high temperature than mountainous area, which has influence on evapotraspiration.

5. SUMMARY

Interaction between soil moisture content and evapotranspiration rate shows active variability in time. There are two important processes controlling their interaction. First process is influence of water table depth on soil water content. Second process characterized by insolation and other and other atmospheric conditions, affecting on evapotranspiration rate. Therefore, Equation (5), which is extension of Priestley-Taylor equation for evapotranspiration is coupled with water balance model, described by Equation (1) in try to consider both water and energy fluxes effecting on this processes. Proposed scheme gives assessment of soil moisture and evapotraspiration at steady condition, considering both water balance and energy flux equations.

REFERENCES

1) Davies, J.A., and Allen, C.D.: Equilibrium, potential and actual evaporation from cropped surfaces in southern Ontario, J. Appl. Meteor., Vol.12, pp.649-657, 1973.

2) Bierkens F. P.: Modeling water table fluctuations by means of a stochastic differential equation, Water resource research, Vol.34, pp.2485-2499, 1998.

3) Hamon W. R.: Estimating potential evapotranspiration, Proc. Am. Civ. Eng. J. Hydraul. Div. Vol.87, pp.107-120, 1961.

4) Wosten J.H.M., Van Genuchten.: Using texture and other soil properties to predict the unsaturated hydraulic conductivity, Soil Science Society of America Journal, Vol.52, pp.1762-1770, 1988.

5) Quinn P.F., Beven K.J. and Lamb R.: The index: how to calculate it and how to use it within the TOPMODEL framework, Hydrological Processes, Vol.9, pp.161-182, 1995.

6) Barton I. J.: A parametrization of the evaporation from nonsaturated surfaces, J. Appl. Meteor., Vol.18, pp.43-47, 1979.