II－13 AN ESTIMATION OF SOIL MOISTURE DISTRIBUTION IN A CATCHMENT

○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

The knowledge of soil moisture distribution in a catchment allows a more accurate representation of the physical hydrological processes on a land surface. The simple budgeting scheme developed by Thornthwaite[1] is suitable to model near-surface hydrology, where detailed data about soil layers, depth to groundwater and vegetation are not available

Despite the fact that application of simple Thornthwaite soil-water budget model has numerous uncertainties, this model have utilized by many researches: Alley[2], Willmott at al.[3], Mintz and Serafini[4], Mintz and Walker[5]. Model requires minimal input data: precipitation, temperature and soil-water holding capacity.

2. DATA

The study area is the 970 km^2 Natori river basin, Japan. Data collected from 1992 until 1997. The elevation of the watershed is from 0 to 1470 m. The soil moisture values were estimated for four land uses: forest area, paddy field, crops field and other land.

The meteorological data were obtained from three observation stations on a daily frequency from the AMEDAS database. The meteorological variables include rainfall data, air temperature and sunshine duration.

3. METHODOLOGY

3-1 Thornthwaite Water Budget Method

The equation for the soil moisture value is

$$W = W_{-1} + (P - E_I) - (E_T + E_S),\ 0 < W < W^* \quad (1)$$

where

W – root-zone moisture at the end of day (mm),

W_{-1} – root-zone moisture at the end of the preceding day (mm),

W^* – root-zone storage capacity, (mm)

P – precipitation, (mm)

E_I – interception loss, (mm)

E_T – transpiration of the plants, (mm)

E_S – soil evaporation, (mm)

And $E_I + E_T + E_S = AE$ is actual evaporation .

$$E_I = \min\{PE, P\}, \quad (2)$$

where PE – potential evaporation

$$E_T + E_S = \beta \cdot (PE - E_I), \quad (3)$$

where $\beta = \dfrac{W}{W^*}$.

3-2 Potential evapotranspiration

Daily potential evapotranspiration PE in mm/day is computed with:

$$PE_i = \begin{cases} 0 & T < 0 \\ \dfrac{16}{N}\left(\dfrac{10 \cdot T_m}{I}\right)^a \cdot \dfrac{DL}{12} & 0 \le T < 26.5 \\ (-415.85 + 32.24T_i - 0.43 \cdot T_i^2) \cdot \dfrac{DL}{12N} & T \ge 26.5 \end{cases} \quad (4)$$

where T_i and T_m, accordingly, are mean daily and monthly air temperature, in (°C) and I is the heat index defined in equation (5) below. The exponent a in equation (4) is a function of the heat index I .

$$I = \sum_{m=1}^{N} (T_m / 5)^{1.514}, \quad (5)$$

where

$$a = 6.7 \cdot 10^{-7} \cdot I^3 - 7.71 \cdot 10^{-5} \cdot I^2 + 1.79 \cdot 10^{-2} \cdot I + 0.49$$

3-3 Darcy's law

$$Q = k \cdot A \cdot \frac{\Delta h}{\Delta l} \quad (6)$$

Q is volumetric discharge, m^3/day, k - hydraulic conductivity, m/day. Δh and Δl are difference in

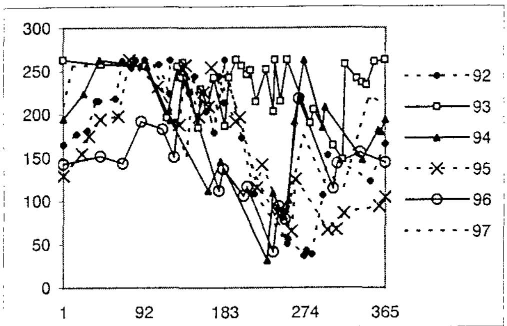

Fig.1 Soil water content variation, mm

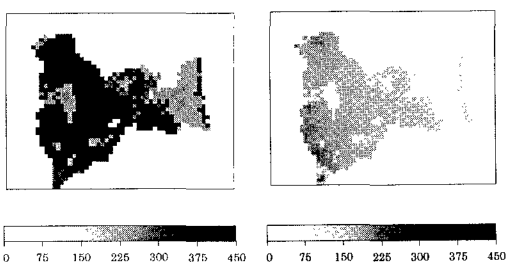

Fig.2 Soil moisture map [mm] for DOY111 and DOY266, 1992.

hydraulic head, treated as elevation difference and distance between current and downstream points, respectively, in m. A is cross-sectional area (m^2).

3-4 Calculation scheme

The soil moisture budget scheme shown in Fig.1 was used for deriving the soil moisture map. Using the elevation map of catchment, the flow direction map is produced. If the soil of upstream point was saturated in the preceding day, the total inflow to current pixel is assumed to be equal to sum of precipitation and inflow in saturated soil from upstream pixel. To produce the soil moisture map for current pixel on the image, Thornthwaite equation was modified as follows:

$$W = W_{-1} + (P - E_I) - (E_T + E_S) + Q_I \qquad (7)$$

where Q_I and Q_O are volume of input and output water that moved horizontally in saturated soil. Q_O value in day i for each point can be calculated using equation (6) Q_O is daily contribution to the downstream point for next ($i+1$) day.

4. RESULTS AND DISCUSSIONS

Using above algorithm, the daily soil moisture maps for a year were obtained for years 1992-1997. Method was applied for vegetation area. The urban area and water body were removed from images.

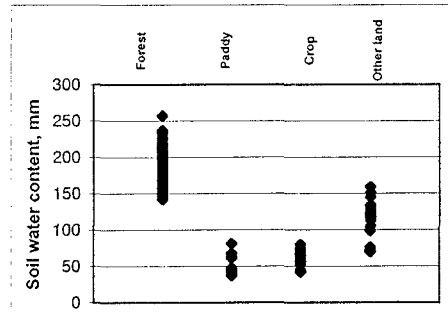

Fig.3 Dispersion of soil moisture for different land uses.

Comparison between soil moisture variations during full climate cycle for different years suggests that there is typical soil variation pattern for Natori river basin (Fig.1). The soil moisture values are reduced until rain season and steeply rise during rain season to maximum values.

The soil moisture maps for days of year (DOY) 111 and 266 shown in Fig.2. In forest area, the soil moisture values much larger than for paddy and crop area, as shown in Fig.3. It is difference effect in root zone depths. There is forest belt in coastal area that gives high soil moisture value in this zone.

5. SUMMARY

The Thornthwaite method was used for calculation the soil moisture distribution. For obtaining the volume of water that moves horizontally in the soil, the Darcy's law was utilized. Using this model, the soil moisture map can be estimated in each point in the catchment throughout the whole year.

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REFERENCES

1)Thornthwaite, C.W.: An Approach Toward a Rational Classification of Climate, Geographical Review, Vol.38, pp.55-94, 1948.

2)Alley, W.M.: On The Treatment Of Evapotranspiration, Soil Moisture Accounting, And Aquifer Recharge In Monthly Water Balance Models, Water Resources Research, Vol.20,pp.1137-1149, 1984.

3)Willmott, C.J., Rowe, C.M. and Mintz, Y.: Climatology of the Terrestrial Seasonal Water Cycle, Journal of Climatology, Vol.5, pp.589-606, 1985.

4)Mintz, Y. and Serafini, Y.V:A Global Monthly Climatology of Soil Moisture and Water Balance, Climate Dynamics, Vol.8, pp.13-27, 1992.

5)Mintz, Y. and Walker, G.K.: Global Fields of Soil Moisture and Land Surface Evapotranspiration Derived from Observed Precipitation and Surface Air Temperature, J. Applied. Meteor., Vol.32, pp.1305-1334, 1993.