A Comparative Study of Model-Driven Soil Moisture Estimates on the Chungju Demonstration Basin

Byong-Ju Lee[1] , Il-Won Jung[2] and Deg-Hyo Bae[3]

1 Graduate Student, Dept. of Civil & Environ. Eng., Sejong Univ., Seoul, Korea
bjlee0704@paran.com
2 Post Doctor, Dept. of Civil & Environ. Eng., Sejong Univ., Seoul, Korea
3 Professor, Dept. of Civil & Environ. Eng., Sejong Univ., Seoul, Korea

Abstract The objectives of this study are to provide the availability of hydrologic and meteorologic data including soil moisture on the AWCI demonstration basin and to evaluate the model-driven soil moisture obtained from hydrologic runoff models. For the simulation of river discharge and soil moisture over the 6,648 km^2 Chungju dam basin in Korea, SWAT, PRMS, VIC and SLURP models are used. The measured soil moisture data revealed that the soil moistures of summer wet season are high and those of winter dry season are low, but the spatial variations at the same periods are very high. Also, the simulated discharges were well presented to the observed ones, but the behaviors of soil moisture were different depending on soil moisture generation structures. Simple arithmetic average from a few point measurements has a possibility to distort the basin average soil moisture.

Key words soil moisture; Chungju dam; SWAT; PRMS; VIC; SLURP

1. INTRODUCTION

Asia monsoon is one of the largest water circulation systems in the world and provides substantial water resources that can be used for power generation, food production and transportation facilities. At the same time, it sometimes causes serious water-related problems such as flood and drought. GEOSS/AWCI was launched for solving water-related problems caused by Asia monsoon water cycle and decided to set up a demonstration basin per each country. The Chungju dam basin with 6,648 km^2 is selected for the Korean demonstration basin.

Soil moisture is one of the most important factors for water cycle processes. It directly affects to the variations of evapotranspiration and surface runoff. However, the measured soil moisture data, especially for those of basin scale rather than point scale, are rarely available. The model-driven soil moisture data or satellite-based soil moisture measurement will be one of the remedies for solving this kind of basin-scale soil moisture data problem.

In this study, we will evaluate the feasibility of model-driven soil moisture data for the integrated data management system over the AWCI demonstration basin. The hydrologic models used in this study are SWAT, PRMS, VIC and SLURP. The measured soil moisture data are used to evaluate the model-driven soil moisture data.

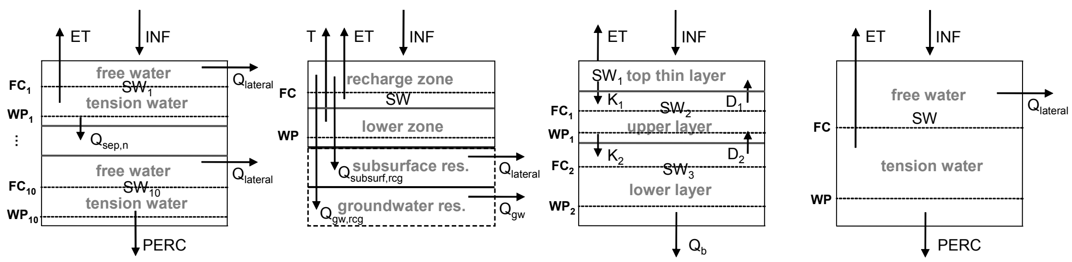
2. MODEL-DRIVEN SOIL MOISTURE

It is important to select runoff model which can represent complex characteristics of basin to estimate model-driven soil moisture data. In this study, we chose semi-distributed continuous simulation models such as SWAT, PRMS, VIC and SLURP. The basic concepts of the model and their soil moisture accounting methods are as follows.

Soil and Water Assessment Tool (SWAT) developed by USDA is a semi-distributed continuous simulation model. This model has been widely applied to predict the effects of climate and vegetative changes, groundwater withdrawals and reservoir management (Arnold et al., 1998). Precipitation-Runoff Modeling System (PRMS), developed by USGS and used for the long-term runoff analysis, is a physically-based deterministic and distributed-parameter modeling system (Leavesley et al., 1983). It is designed to analyze the effects of precipitation, climate, and land use on streamflow and general basin hydrology. Variable Infiltration Capacities (VIC)-nL model is a land surface model based on the main hydrological process in which the interaction of atmosphere, vegetation and soil, the dynamic change of water and energy flux are considered. One distinctive feature of this model is that it represents the sub-grid spatial heterogeneity of precipitation with sub-grid spatial variability of soil infiltration capability (Liang et al., 1994). Semi-distributed Land Use-based Runoff Processes (SLURP) is a conceptual model which is capable of use as a fully-distributed hydrological model, although normally used in semi-distributed form (Kite, 1978).

The soil-moisture accounting method for the selected models is generally performed as the algebraic summation of all moisture accretions to and depletions from the soil profile, shown in Fig. 1. The depletions usually include evapotranspiration, lateral flow and percolation, while the accretions are rainfall and snowmelt input to the system. These models, however, obviously have different structure based on their model development purposes and simulation capabilities. The soil profile of SWAT can be divided into a maximum of 10 layers and each soil layer is divided into the free water and tension water fields according to the boundary of field capacity (FC_i) and wilting point (WP_i). Total soil water(SW) is a summation of each SW_i on the soil layers.

However, the soil profile of PRMS is divided into two layers: the recharge zone and the lower zone. Losses from the recharge zone occur from evaporation and transpiration, while those from the lower zone are transpiration only. The evapotranspiration losses are a function of available soil-moisture storage. The attempt to satisfy potential evapotranspiration is worked from the recharge zone storage before water will move to the lower zone. When soil-zone storage reaches maximum available water capacity (FC-WP) of soil zone, all additional infiltration is routed to the subsurface and ground-water reservoirs. Land surface of VIC model is divided to different land covers and bare soil horizontally and partitioned into 3 layers which include top soil layer (usually taken as 100 mm depth from the surface), the upper soil layer and the lower soil layer vertically. Quick bare soil evaporation following small summer rainfall events happens in the top soil layer; the upper soil layer is designed to represent the dynamic change of soil moisture and the production of runoff when rainfall happened; soil moisture change and baseflow mainly occurred in the lower soil layer of the model. K_i and D_i in Fig. 1 is hydraulic conductivity (mm/d) and diffusivity (mm/mm), respectively. In the SLURP, rainfall or snowmelt enters into the soil water storage as long as the infiltration capacity is not exceeded. Otherwise, water is released as surface runoff. When water from the soil water storage is higher than the field capacity (FC), then the excess is spilled as Q_{latral}. Percolation takes place at a rate depending on the current store contents, the retention constant and the wilting point.



a) SWAT b) PRMS c) VIC d) SLURP

Fig. 1 Conceptual structure of soil water movement on SWAT, PRMS, VIC and SLURP

3. SOIL MOISTURE MEASUREMENT

Soil moisture data provided by Agriculture Weather Information System is used in this study, as shown in Fig. 2. Among 113 observation stations, we used the data of 50 stations that have multi-year records. TDR (Time Domain Reflectometry) is used to measure the soil moisture and the percent (%) of soil water content for total soil volume is adopted as an unit of the measurement. The monthly averages for the stations during the period 2004-2005 are shown in Fig. 3. It can be seen that the soil moisture is higher during the rainy season (July-Sept.), while lower during dry season (Dec.-Jan.). Although in the same month, the soil moisture is different up to 5 times depending on the region of the station. Some of the stations located in northern part have the increase of soil moisture in March due to snowmelt effect.

4. MODEL APPLICATION

The Chungju dam basin, which is about 6,648 km^2, is decided to the Korean demonstration basin of AWCI and selected for the soil moisture study. There exist 56 precipitation stations, 21 discharge stations and 12 meteorological stations and routinely collect the hydrological and meteorological data that are essential for configuration of water cycle behaviors. However, only 2 stations are operating for the soil moisture measurement. We used 4 different hydrologic models for the soil moisture computations. Before generating soil moisture from the models, all the models are calibrated for the model parameter estimation and verified for confirming their model performance for 10-year data (1996-2005 for the calibration and 1986-1995 for the verification). Some of the simulated daily runoff, as a function of transformed flow (Hogue et al., 2000), are shown in Fig 4. The simulated flow data are well fitted to the measured values for both high and low water levels. The Nash-Sutcliffe efficiencies between the simulated and the measured flows were ranged on 0.61-0.86. Fig. 5 shows the model-driven monthly averaged soil moisture ratios in addition to the observations during 2003-2004. These ratios are varied on the range of 10-30% and the model-driven soil moistures were different from models depending on evapotranspiration and runoff mechanisms.

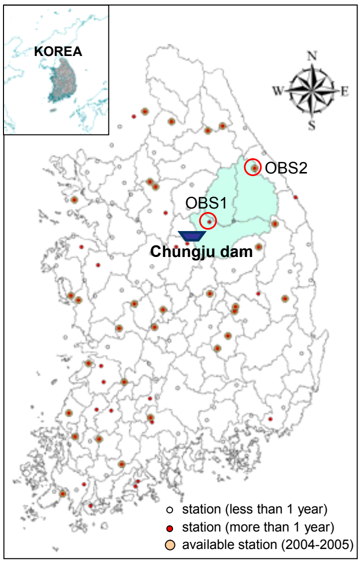


Fig. 2 The status of soil moisture station

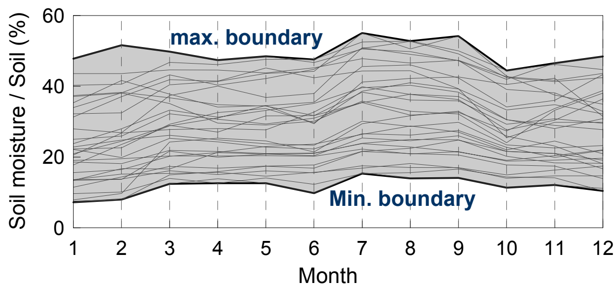


Fig. 3 The average monthly soil moisture(%) on the 30 sites.

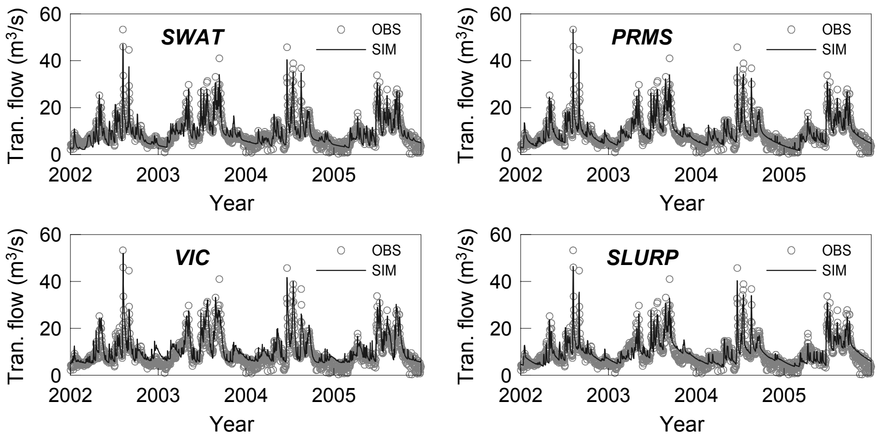


Fig. 4 The daily measured and simulated flow from each model.

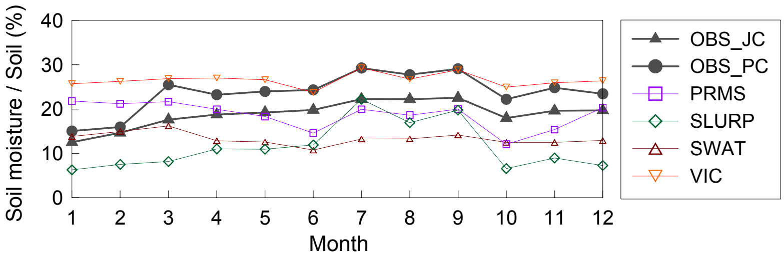


Fig. 5 Monthly averages of the measured and the simulated water contents

5. CONCLUSION AND RECOMMENDATIONS

The spatial and temporal variations of soil moisture are important for the Asia water cycle investigation, but difficult to maintain the measurement data covering the whole water cycle domain. In this study, we provided the current measurement of soil moisture in Korea and analyzed the monthly variations. We also applied 4 different semi-distributed hydrologic models for soil moisture generations on the AWCI demonstration basin.

In general, the measured soil moisture data revealed that the soil moistures of summer wet season are high and those of winter dry season are low, but the spatial variations at the same periods are very high. It represents that the simple arithmetic average of point soil moisture measures within the study basin area has a possibility to distort the true behavior of soil moisture. Also, the model-driven soil moistures are different from model to model, although each model was calibrated for the model parameter estimates and verified for the model performance by using observed and simulated river discharges. It maybe caused by different soil moisture structures and evapotranspiration computation mechanisms. Further investigations will be necessary, especially focusing on inter-comparison analysis of soil moisture and evapotranspiration. Also, the use of satellite data will be another approach for soil moisture generations.

Acknowledgements

This research was supported by a Natural Hazard Mitigation Research (Development of real-time inland flooding prediction techniques considering urban characteristics) in Korea.

REFERENCES

Arnold, J.G.., Srinivasan, R., Muttiah, R.S. & Williams, J.R. (1998) Large area hydrologic modeling and assessment-Part I: model development. J. Am. Water Resour. Assoc. **34**(1), 73-89.

Hogue, T.S., Sorooshian, S., Gupta, V.K., Holz, A. & Braatz, D. (2000) A multistep automatic calibration scheme for river forecasting models, J. Hydrometeorology, **1**, 524-542.

Kite, G.W. (1978) Development of a hydrological model for a Canadian watershed, Canadian Journal of Civil Engineering, **5**(1), 126-134.

Leavesley, G.H., Lichty, R.W., Troutman, B.M., & Saindon, L.G. (1983) *Precipitation-Runoff Modeling System, User's manual*, Water- Resources Investigations, 83-4238.

Liang X., Lettenmaier D.P., Wood E.F. & Burges S.J. (1994) A simple hydrologically based model of land surface water and energy fluxes for general circulation models. J. Geophys. Res., **99**(D7), 14415-14428.