

ABSTRACT

Bhuiyan, Mohammad. Ph.D., Purdue University, May 2017. Improved soil moisture accounting in hydrologic models. Major Professor: Venkatesh M. Merwade

Uncertainty is inherent in any hydrologic prediction; an apparently well-performing model can be pseudo-accurate giving right answers for wrong reasons. Soil Moisture Accounting (SMA), by playing an important role in partitioning water between surface and sub-surface components, regulates the overall physical consistency and predictive skills of a hydrologic model. Given the complex cause-and-effect relationships among soil moisture, surface runoff and evapotranspiration, this dissertation explores multiple avenues to improve SMA with the aim of improving the overall hydrologic model predictability. Specifically, Soil and Water Assessment Tool (SWAT) is used on four U.S. watersheds to accomplish the following three objectives: (1) evaluation of a multi-objective calibration approach for hydrologic models using remotely sensed soil moisture estimates; (2) re-conceptualization of surface runoff mechanism by incorporating a time-dependent, soil moisture-informed Curve Number method; and (3) direct ingestion of spatially distributed remotely sensed potential evapotranspiration in SWAT to improve the overall energy and water balance. To meet the level of interoperability required between a complex hydrologic model and the remotely sensed “big data” (objectives 1 and 3), a key contribution of this dissertation is the development of a new, adaptive tool that can perform rapid extraction and processing of satellite observations at user-defined spatial resolution.

The first objective involves evaluating the relative potential of spatially distributed surface and root zone soil moisture estimates in the calibration of SWAT model. Considering two agricultural watersheds in Indiana, USA, the proposed calibration approach is performed using remotely sensed Advanced Microwave Scanning Radiometer-Earth Observing System (AMSR-E) surface soil moisture (~1 cm top soil) estimates in sub-basin/HRU level together with observed streamflow data at the watershed’s outlet. Although application of remote sensing data in calibration improves surface soil moisture simulation, other hydrologic components such as streamflow and deeper layer moisture content remain less affected. An extension of this

approach to apply root zone soil moisture estimates from limited field sensor data showed considerable improvement in those cases. Difference in relative sensitivity of parameters and reduced extent of uncertainty are also evident from the proposed method, especially for parameters related to the sub-surface hydrologic processes.

The second objective involves incorporating a time-dependent SMA based Curve Number method (SMA_CN) in the SWAT model and compare its performance with the existing CN method by simulating the hydrology of two agricultural watersheds in Indiana, USA. Results show that fusion of the SMA_CN method in SWAT better predicts streamflow in all wetness conditions, thereby addressing issues related to peak and low flow predictions by SWAT in many past studies. Comparison of the calibrated model outputs with field-scale soil moisture observations reveals that the SMA overhauling enables SWAT to represent soil moisture condition more accurately, with better response to the incident rainfall dynamics. While the results from the newly introduced SMA_CN method are promising, functionality of this method would likely to be more pronounced if applied for sub-daily hydrologic forecasting.

Source-attribution of evapotranspiration uncertainty in a hydrologic model and evaluation of a remote sensing based solution are the two main aspects of the third objective. Using SWAT for three US watersheds from Indiana and Arkansas, this study first addresses the effects of parameter equifinality, energy related weather input-uncertainty and lack of geo-spatial representation on evapotranspiration simulation. In every case, remotely sensed 8-day total actual evapotranspiration (AET) estimate from Moderate Resolution Imaging Spectroradiometer (MODIS) is used as the reference to evaluate model outcome. Results from these assessments indicate the likelihood of a pseudo-accurate model that invariably shows high streamflow prediction skills despite having severely erroneous spatio-temporal dynamics of AET. As a remedial measure, a hybrid daily PET estimate, derived from MODIS and the North American Land Data Assimilation System phase 2 (NLDAS-2), is directly ingested at each Hydrologic Response Units (HRUs) of the SWAT model to create a new configuration called SWAT-PET. Noticeably increased accuracy of three water balance components (soil moisture, AET and streamflow) in SWAT-PET, being evaluated against completely independent sources of observations/reference estimates (i.e. field sensor, satellite and gauge stations), proves the efficacy of the proposed approach towards improving physical consistency of hydrologic

modeling. While the proposed approach is evaluated for a past period, the main motivation here is to serve the purpose of hydrologic forecasting once near real-time PET estimates become available.

Although three objectives are accomplished through separate studies, the proposed approaches are designed to function in an integrated way if applied together in a particular hydrologic model. While designing the methodologies, main focus was to ensure replicability such that research results from this dissertation can be readily translated into practice.