Enhancing soil drainage and groundwater recharge estimations by using coupled plant-soil-water and groundwater flow modeling

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ABSTRACT
Assessing agrochemical leaching and loading to groundwater requires accurate soil drainage data. In many cases, deep drainage flux corresponds to groundwater recharge, which is essential information for groundwater resource management. Accurately measuring soil drainage is challenging. As a result, it is commonly estimated from unsaturated flow modeling. In unsaturated flow modeling, soil moisture measurements are often used for model calibration and verification in the absence of reliable drainage measurements. However, Sorensen et al. (2014) showed that the value of soil moisture data as the sole diagnostic for groundwater recharge modeling studies is questionable because they found that four different unsaturated flow models honored the same moisture data well, but produced largely different recharge values. A coupled LEACHM and MODFLOW approach, which allows soil moisture, groundwater level, and stream flow (e.g., base flow) measurements can be used to constraint drainage estimation, is proposed to enhance soil drainage estimation. This approach was tested in the Cross River watershed (45 km^2) in Prince Edward Island (PEI). First, a LEACHM model, which is a deterministic 1D model that simulates plant water uptake, and flow and solute transport in subsurface (Hutson, 2003), was developed. In LEACHM, weekly potential evapotranspiration (ET) was calculated using the Linacre method and was converted to daily evapotranspiration by multiplying ET with crop cover fraction factor, which was calculated by the crop growth subroutine. Precipitation, daily air temperature and daily evapotranspiration were used to define upper boundary condition and source/sink terms of the soil column for solving the Richards equation. Soil water retention was predicted from soil texture, bulk density, and organic matter content using the regression equation developed by Rawls and Brakensiek (1985). Potato-Barley-Red clover ration for 2011-2016 was assumed to reflect vegetation water uses in the Cross River watershed, and was defined in the LEACHM model by using the crop data in Jiang et al. (2011). The LEACHM model was calibrated using soil moisture data. Second, a watershed-scale steady state MODFLOW model was developed. The MODFLOW model was first calibrated against water level measurements. The LEACHM and MODFLOW models were then coupled loosely by utilizing the daily drainage predicted by LEACHM as recharge for the MODFLOW. Using LEACHM-predicted daily drainages as recharge, the MODFLOW model respected the measurements of daily groundwater level and base flow very well except for some short periods when extremely deep snow cover existed. Under the deep snow cover conditions, manual adjustments on drainage prediction were required to improve model fit. This work shows that groundwater level measurements and base flow data can be used to constraint soil drainage estimation via coupled unsaturated flow and groundwater flow modeling, given that water table is relatively shallow and responds quickly to drainage events. The coupled modeling process can potentially help identify if unsaturated flow modeling can produce reliable soil drainage/recharge estimation.