A Fully Coupled Surface Water Storage and Soil Water Dynamics Model for Characterizing Hydroperiod of Geographically Isolated Wetlands

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Abstract

Hydrological modeling of wetlands is important for reliable estimation of biogeochemical processes in soils subject to periodically inundating conditions. The present study has developed a wetland module in the Richards-equation-based SWAT model to fully couple the surface water storage and soil water dynamics. The wetland module was tested using observed daily water level data from four wetlands (including restored and natural wetlands with and without impermeable soil layers) in the Choptank River Watershed, Maryland, USA. After the wetland module was calibrated, simulated daily water level and observed data were compared and evaluated using three statistics, i.e., percent bias (Pbias), coefficient of determination (R2), and Nash-Sutcliffe coefficient (NS) from 2016 to 2017. The results showed that, in general, the wetland module regenerated hydroperiods for both restored and natural wetlands with and without impermeable soil layers; specifically, the module was able to accurately model saturation conditions for different soil layers corresponding to wet and dry periods in plant growing seasons; the wetland module had the tendency to generate better results for natural wetlands because restored wetlands tended to have mixed plant types which caused difficulty for accurate estimation of evapotranspiration; the ability to accurately describe inundation conditions for wetlands is important for biogeochemical modeling so that the newly developed wetland module has a great potential in enhancing simulation of biogeochemical cycles not only at the site scale but also at the watershed scale.

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Introduction

■Hydrological modeling of wetlands is important for reliable estimation of biogeochemical processes in soils subject to periodically inundating conditions.

■A new wetland model with enhanced functions describing the interaction between surface water storage and soil water dynamics was developed in Soil and Water Assessment Tool (SWAT).

■The new wetland model was integrated with Richards equation to solve soil water dynamics.

■The new wetland model was tested using monitored water level data from restored and natural wetlands with and without impermeable soil layers in the coastal plain of the Chesapeake Bay.

Wetland Model Development

■ Surface Water Storage

$$\Delta SWS = P + R_{in} - R_{out} - E - S$$

ΔSWS: water storage change; P: precipitation; R_{in}: upland inflow; E: evaporation; R_{out}: surface runoff; S: seepage.

■ Wetland Evaporation

$$E = E_w \cdot \left(\frac{SA}{HRUA}\right) + E_s \cdot \left(1 - \frac{SA}{HRUA}\right)$$

E_w: evaporation from water surface; E_s: evaporation from soil surface; SA: water surface area; HRUA: HRU area.

■ Seepage

S is determined by the minimum saturated hydraulic conductivity of soil layers and the total volume of effective porosity.

■ Groundwater Flow: $Gw = k\_eff \cdot Wth / L$

Gw: groundwater discharge; Wth: water table height relative to the reference elevation; L: distance from the wetland to the main channel; k_*eff*: effective saturated hydraulic conductivity.

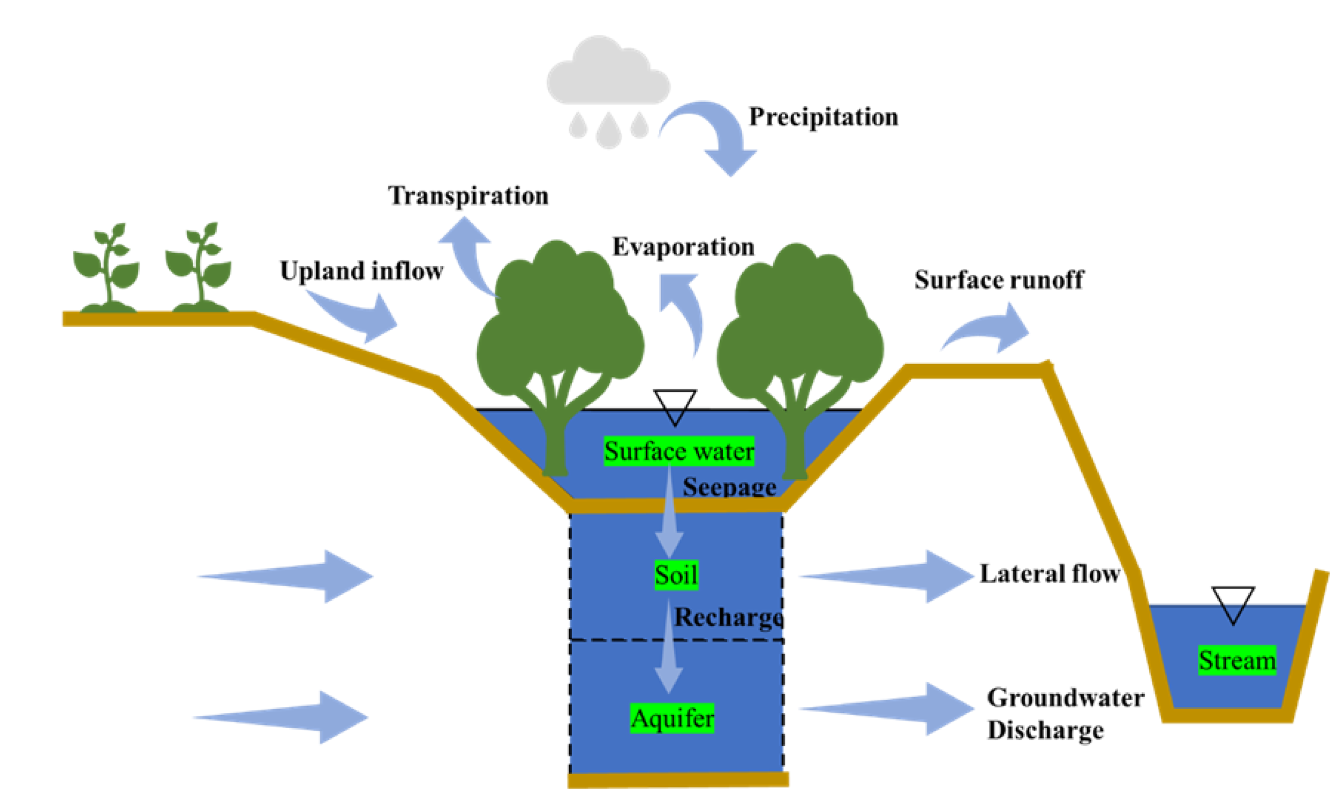

Fig. 1 Conceptualized wetland water balance and hydrological processes simulated by the wetland model.

■ Soil Water : Richards equation

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left[k \cdot \left(\frac{\partial (h - h_e)}{\partial z}\right)\right] - Q$$

Θ: soil water content; t: time step; z: depth below soil surface; k: hydraulic conductivity; h: soil matric potential; Q: soil water sink term; h_e: equilibrium soil matric potential.

Study Site and Data

■ Water levels for restored and natural wetlands have been monitored since 2016 at Site #1 outside Greensboro Watershed (GW) and Site #2 within GW (Fig 2).

■ Site #2 is characterized by a high level of saturated hydraulic conductivity (two wetlands without impermeable soil layers) while Site #1 (two wetlands) includes impermeable soil layers.

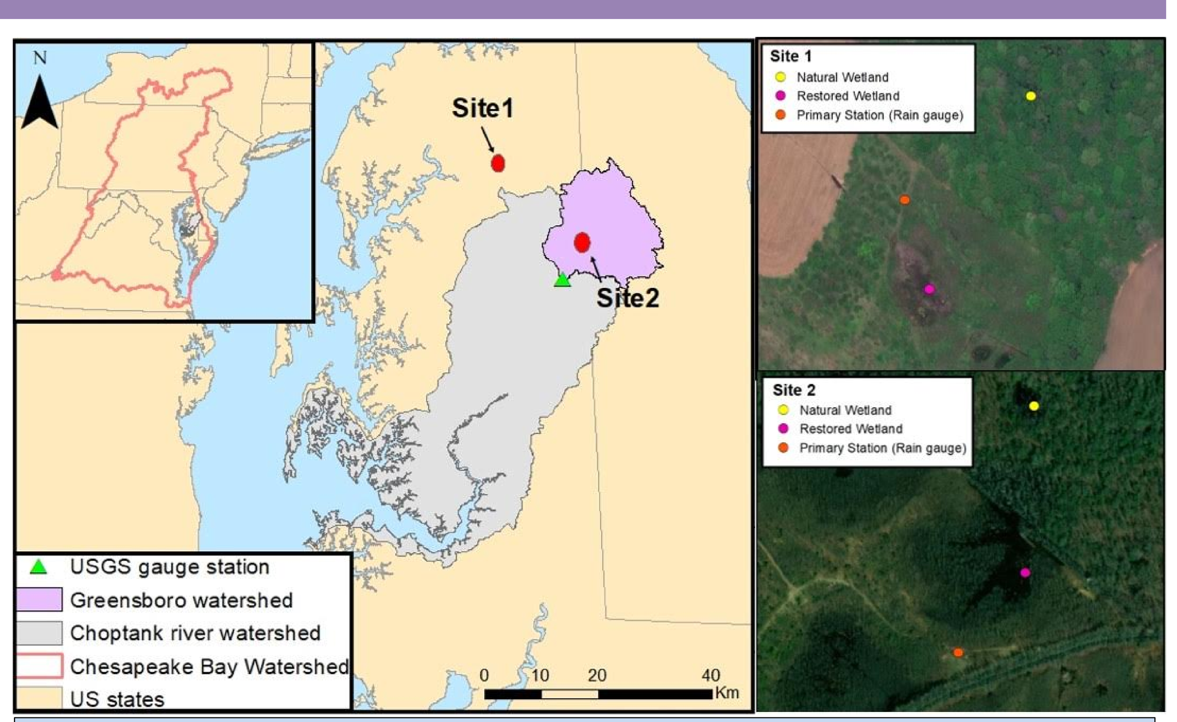

Fig. 2 Location of two wetland sites.

Results

■ The wetland model was used to simulate the water level at the natural and restored wetlands in Site #1 and #2.

■ Model performance was evaluated using coefficient of determination (R^2), Nash-Sutcliffe coefficient (NS), and percent bias (P_{bias}): $P_{bias} = 100 \cdot (O_{avg} - P_{avg})/O_{avg}$

O_i and P_i are the observed and predicted values; O_{avg} and P_{avg} are the average of the observed and predicted values.

Table 1. Wetland model performance evaluation.

Wetland	R^2	NS	P_{bias} (%)
Restored_ Site #2	0.76	0.74	14.6
Natural_ Site #2	0.91	0.90	-3.6
Restored_ Site #1	0.71	0.43	5.2
Natural_ Site #1	0.79	0.64	1.7

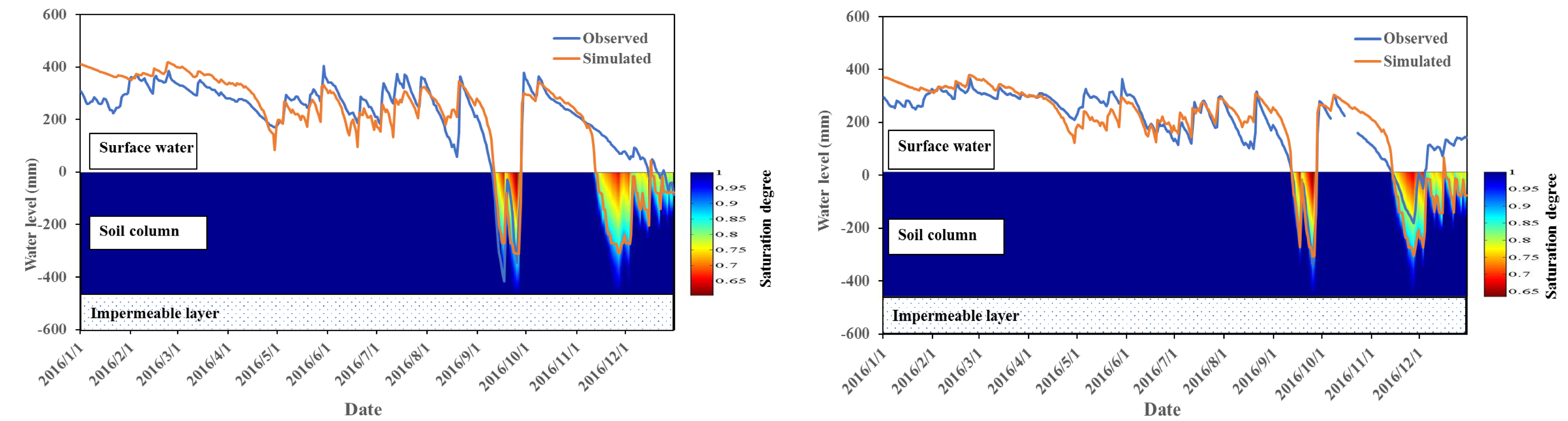

Fig. 3 Observed vs. simulated daily water level for the restored (left) and natural (right) wetlands at Site #1 from 2016 to 2017.

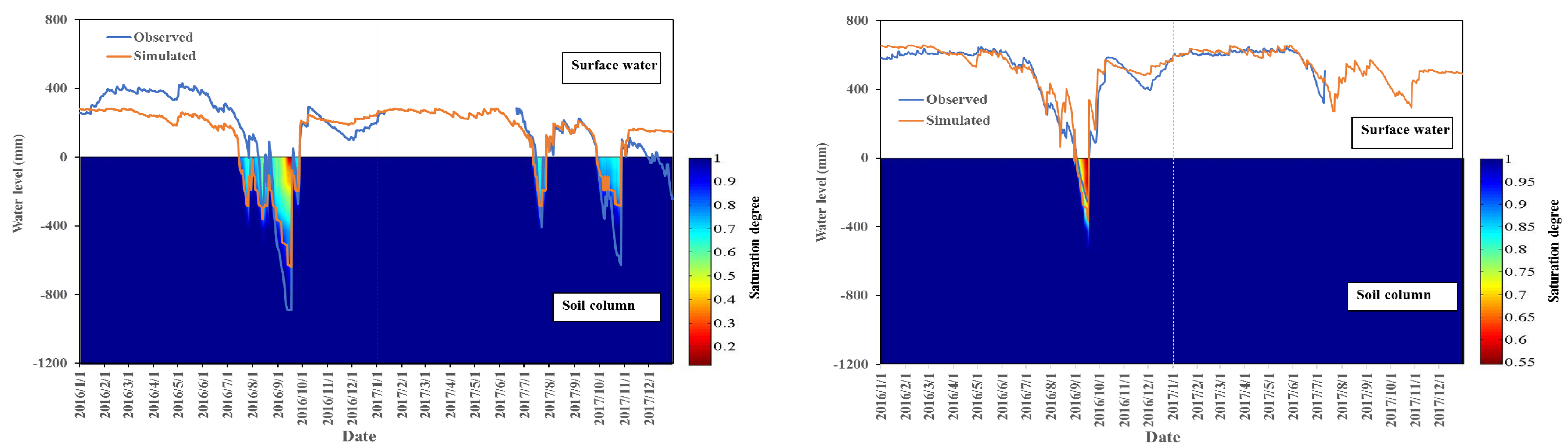

Fig. 4 Observed vs. simulated daily water level for the restored (left) and natural (right) wetlands at Site #2 in 2016.

Summary and Acknowledgement

■ The wetland model reproduced hydroperiods for both restored and natural wetlands at the two sites with and without impermeable soil layers; saturation conditions for different soil layers corresponding to wet and dry periods were also well described, especially for plant growing seasons; the model holds the promise to enhance simulation of biogeochemical cycles at both the site and watershed scale through integration with SWAT.

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