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Hydrological simulation in a basin of typical tropical climate and soil using the SWAT Model Part II: Simulation of hydrological variables and soil use scenarios

Donizete dos R. Pereira[a,*], Mauro A. Martinez[b], Demetrius D. da Silva[b], Fernando F. Pruski[b]

[a] Institute of Agrarian Sciences—UFV/Campus Florestal, Rodovia LMG 818, km 6, CEP 35, Florestal, MG, Brazil
[b] Department of Agricultural Engineering—DEA/UFV, Avenida PH Rolfs, Campus Universitário, CEP 36, Viçosa, MG, Brazil

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ABSTRACT

Study region: The study was developed for the Pomba river basin, which is located in southeast region of Brazil in the continent of South America.
Study focus: Hydrological simulation may be used to estimate the water availability, flood streamflows and the basin's hydrological response due to changes in soil use. Thus, aimed to apply the SWAT model, version 2005, to simulate (i) the minimum and maximum annual daily streamflows associated to different return times, (ii) minimum reference streamflows for water rights, and (iii) scenarios of changes in soil use. Were simulated the following scenarios of soil use: S1—preservation, considering the permanent preservation areas (PPAs); S2—reforestation expansion and S3—agricultural expansion, considering the replacement of 10% of the basin's total area covered with pastures for eucalyptus and crops, respectively. The current use (S0) being employed as the baseline.
New hydrological insights for the region: It was observed that the values of maximum and minimum annual daily streamflows with different return times, and of minimum reference streamflows for water rights simulated by the SWAT did not statistically differ from the values observed according to *T*-test at 5% probability level. When assessing the effects of changes in soil use, a mean annual reduction in runoff from 13.6, 4.0, and 6.5 mm was observed for scenarios S1, S2, and S3, respectively.

1. Introduction

Carrying out hydrological studies in basins arises from the need of understanding the water balance, the processes that control water movement and their likely impacts on the amount and quality of water.

Hydrological simulation of basins is one of the main water resource planning and management tools, developed to assess the processes that control water movement at different spatial and temporal scales (Spruill et al., 2000). It may be used to estimate water availability, to predict short and mid-term streamflows, and to analyze the hydrological response of a basin due to changes in soil use and cover. From the agricultural standpoint, its importance is mainly to characterize the reference

* Corresponding author.
E-mail addresses: donizete.pereira@ufv.br (D. dos R. Pereira), mmauro@ufv.br (M.A. Martinez), demetrius@ufv.br (D.D. da Silva), ffpruski@ufv.br (F.F. Pruski).

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streamflows for water use rights, crucial for irrigation projects (Viola et al., 2009). The reference streamflow means setting a streamflow value that represents the upper water use limit in a water stream and is an appropriate procedure to protect rivers using a low-risk base streamflow (Harris et al., 2000; Silva et al., 2006).

Verifying the maximum, minimum, and reference water rights streamflows through the simulated series enables analyzing the application of the hydrologic model as a water resource planning and management tool (Andrade et al., 2013; Pereira et al., 2014a; Viola et al., 2009). Thus, validating the behavior of the hydrological model in face of the maximum streamflows—used to study floods—and minimum streamflows—with multiple purposes—is fundamentally important and allows the model's performance in simulating extreme values to be verified (Viola et al., 2009). One of the tools used to determine the water availability in a given basin is the permanence curve, which provides the frequency at which a certain streamflow is exceeded, and it is often employed to determine the reference values of minimum streamflows. Reference values often extracted from this curve are $Q_{90\%}$ and $Q_{95\%}$, which represent the streamflows exceeded or equaled in 90% and 95% of the time, respectively.

The SWAT hydrologic model has been widely used in the simulation of daily streamflows in basins, however very few studies assess the model precision for estimating the daily stream flow which allows for the verification of the basin water availability (Pereira et al., 2014a; Andrade et al., 2013). Pereira et al. (2014a) applied the SWAT model for Galo Creek basin, which has a 942 km^2 of drainage area, located in the Espírito Santo State, Brazil, and obtained appropriate simulations of the minimum annual daily streamflow (mean absolute error 10%) and reference of streamflow for water rights ($Q_{90\%}$ and $Q_{95\%}$) (mean absolute errors of 5.6% and 4%, respectively), however the model was not appropriate for estimating the maximum annual daily streamflow (mean absolute error 30.8%). Likewise, Andrade et al. (2013) applied the SWAT model in a basin of the Alto Rio Grande region, Minas Gerais State, and concluded that the model is applicable for the simulation of minimum and maximum daily streamflow, and those associated with different time regimes of streamflow maintenance, in particular the $Q_{90\%}$ (absolute error of 14.9%, average of calibration and validation) and the ($Q_{95\%}$) (mean absolute error 26.8%, average of calibration and validation). Nevertheless, there have been few studies that assess the model performance to simulate the maximum and minimum annual daily streamflow by testing different return times, which is important for the design of hydraulic structures.

The SWAT model also has been widely used to evaluate the impacts of soil use and cover upon the hydrologic regime of basins. These assessments are fundamental for managing and planning the use of water resources (Du et al., 2013; Nie et al., 2011), and usually includes spatial and/or temporal assessment (Ghaffari et al., 2009; Miller et al., 2002 Nie et al., 2011). Removing forest cover may lead to severe impacts on water resources, affecting the basin's hydrology by changing interception, infiltration, evapotranspiration, and groundwater recharge rates (Baker and Miller, 2013). These changes may potentially cause floods in cities and change the streamflow's regime. However, there is no consensus regarding how deforestation in tropical regions impacts a basin's hydrology (Baker and Miller, 2013; Chandler, 2006). Several studies have shown that reforestation in sub-tropical environments led to a reduction in base runoff due to the higher evapotranspiration rates (Locatelli and Vignola, 2009; Notter et al., 2007; Pereira et al., 2014b; von Stackelberg et al., 2007). Nevertheless, removing vegetation may cause an increase in base runoff if the water infiltration capacity of the soil remains unchanged (Baker and Miller, 2013; Brüijnzeel, 2004).

von Stackelberg et al. (2007) used the SWAT model for simulating the hydrologic impacts of a pine forest (*Pinus taeda*), which was introduced as replacement for pastureland in Tacuarembó river basin, Uruguay (a drainage area of 107.7 ha); and estimated a streamflow reduction of approximately 23%. In Brazil, three land use scenarios were compared to baseline conditions using the SWAT model for the Galo Creek (drainage area of 943 km^2) located in Espirito Santo State, over a seven-year period (Pereira et al., 2014b). In the first scenario, the permanent preservation areas (PPAs) of the basin were considered to be covered by native vegetation (Atlantic Forest). In the second and third scenario almost all the land use was considered for the conservation of forest and pasture, respectively. The first, second and third scenario represent a soil covered by native forest of 76, 97 and 0%, respectively, in comparison to the actual scenario of 54% forest cover. For the first and second scenario there was a reduction of runoff of almost 6% and 11.5%, respectively. In the third, there was a runoff increase of over 14%. A similar land use impact study was conducted with SWAT model by Rodrigues et al. (2015) for the Pará river basin (drainage area of 12,300 km^2), located in Minas Gerais, Brazil. The authors compared the original land cover in the basin, which was dominated by the Atlantic Forest and Cerrado biome vegetation, versus the current land use which included 38% pasture, 7.5% eucalyptus forest and 4.5% of perennial and annual crops, and further represented overall declines of about 50% and 25% of the Atlantic Forest and Cerrado biome vegetation. It was concluded that the conversion of native vegetation to the current mix of land use has resulted in a 10% increase of streamflow at the basin outlet.

However, so that the SWAT model is widely disseminated worldwide, studies still must be carried out under several edaphoclimatic conditions, mainly in tropical conditions, where the effects of changes in soil use and cover on the hydrological regime of basins is controversial. In view of that, the present study aims to publicize the results obtained for a basin with climate and soil typical of tropical conditions, which is why the Pomba river basin, located in southeast Brazil, was chosen.

The SWAT model, version 2005, previously calibrated for the Pomba river basin with a control section in Astolfo Dutra, was applied to simulate (i) the minimum and maximum annual daily streamflows with different return times, (ii) minimum reference streamflows for water rights, and (iii) the basin's hydrological behavior for different soil use scenarios.