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Vinícius Augusto de Oliveira[1a+], Carlos Rogério de Mello[1b], Marcelo Ribeiro Viola[1c], Raghavan Srinivasan[2]

LAND-USE CHANGE IMPACTS ON THE HYDROLOGY OF THE UPPER GRANDE RIVER BASIN, BRAZIL

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HIGHLIGHTS

SWAT model effectively estimates the streamflow in the Upper Grande River Basin.

Deforestation of native vegetation may lead to an increase in runoff and peak flow.

Reforestation of native vegetation may lead to an increase in infiltration and soil-water holding capacity.

Keywords:
Deforestation
Hydrological modeling
Reforestation
Scenarios
SWAT model

ABSTRACT

Land-use changes are considered one of the most important factors that affect the water resources. The objective of this study was to investigate the potential impacts of land-use changes on the hydrological behavior of the Upper Grande River Basin, southern Minas Gerais state, Brazil, based on different land-use scenarios using the SWAT model. For this purpose, daily streamflow records from the Macaia gauge station were calibrated and validated under the current land-use. To assess land-use change impacts four land-use scenarios were developed following official environmental planning reports: S_1 and S_2 – conversion of forest into pasture of 20 and 50%, respectively; S_3 and S_4 – conversion of pasture into forest of 20 and 50%, respectively. The results have showed that, in general, the deforestation scenarios (S_1 and S_2) presented an increase in total runoff and peak flow and a decrease in the baseflow and evapotranspiration, whereas the reforestation scenarios (S_3 and S_4) have showed the opposite. The results showed that the land-use changes can generate positive impacts, such as reduction of surface runoff and increase in the baseflow, as well as negative ones, like the increase of soil erosion and flood risks.

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+Correspondence:
aovinicius@gmail.com

[1] Federal University of Lavras, Lavras, Minas Gerais, Brazil - ORCID: 0000-0003-1324-0284[a], 0000-0002-6033-5342[b], 0000-0002-3910-0987[c]
[2] Texas A&M University. Ecosystem Science and Management Department. College Station, TX. United States of America - ORCID: 0000-0001-8375-6038

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INTRODUCTION

Brazil is strongly dependent of the surface water resources for economy and, therefore, very susceptible to the weather variability and changes in the hydrological regime. The country relies in its water resources to generate electric energy, where almost 78% of all energy is produced by hydropower plants (EPE, 2016; Oliveira et al., 2017).

The Grande River Basin is one of the most important Brazilian hydrologic regions regarding water availability and electric energy production. Its headwaters are located in the southern Minas Gerais state, in which three large reservoirs are installed. Thus, streamflow yields in this region is extremely important, since it directly supplies three hydropower plants (Camargos, Itutinga and Funil) and play an important role in hydrology regulating other downstream reservoirs, highlighting Furnas hydropower plant (Oliveira et al., 2017; Viola et al., 2013).

Land-use, hydrology and hydropower facilities are directly linked. Land-use changes have been considered one of the most important factors that affect water budget in watersheds (da Silva et al., 2018). It is well-established that land-use changes may alter the water balance components, which can cause both positive and negative impacts (dos Santos et al., 2018; Bruijnzeel, 1990).

In general, a reduction in forested areas tends to increase the annual runoff, and, due to a reduction in the soil-water infiltration capacity, an increase in the surface runoff is expected, which can accelerate the erosive processes, reducing the water availability and affecting the water quality (Alvarenga et al., 2016; Can et al., 2015; Carvalho-Santos et al., 2016).

On the other hand, grassland shift into forest contributes with a reduction of the surface runoff as both infiltration rates and soil-water holding capacity increase due to the increase of organic matter and preferential flows formed in the soil profile (Pinto et al., 2015). Consequently, a reduction of soil erosion and sediment load transportation is expected as well as a reduction of flood risks and water shortages. Also, an increase of forested areas promotes a reduction in runoff, mainly due to an increase in the water consumption by the trees and decrease of peak flows over the hydrological year (Carvalho-Santos et al., 2016; Viola et al., 2014; Bruijnzeel, 1990).

Hence, understanding the mechanisms between land-use and hydrology are essential to improve both water and land-use management. In this regard, paired catchment experiments have been used in studies such as Bruijnzeel (1990) and Sahin and Hall (1996). Although deemed reliable, experimental methods to assess hydrological processes are generally expensive and time consuming. Therefore, assessing the impacts of land-use changes using hydrological models can be a reliable scientific alternative despite of the limitations and uncertainties of the models to represent the dynamic of the hydrological processes, especially the infiltration-runoff and groundwater recharge (dos Santos et al., 2018; Mello et al., 2016).

Hydrological models, such as the Soil and Water Assessment Tool (SWAT), have been successfully used for assessing land-use change impacts on water quantity and quality in many studies worldwide such as Aich et al. (2016), Mwangi et al. (2016), Zhao et al. (2016), Bieger et al. (2015), Serpa et al. (2015), among others. Also, this assessment has been performed in some watersheds in Brazil, such as Hernandes et al. (2018), Lamparter et al. (2018), dos Santos et al. (2018), Pereira et al. (2016) and Rodrigues et al. (2015).

In this regard, the objective of this research was to assess the potential impacts of land-use changes on the hydrological behavior of the Grande River Basin headwaters under different land-use scenarios using the SWAT model, providing information to enhance water planning and management in this basin as it is one of the most important hydrologic regions regarding hydropower production in Brazil.

MATERIAL AND METHODS

Study area

The assessment of impacts of land-use on hydrology was conducted in the southern Minas Gerais state, Brazil. The basin was delineated from Macaia gauge station, in the Grande River Basin headwaters, located at the latitude 21° 8’ 41” S and the longitude 44° 54’ 50” W, presenting a drainage area of 15409.2 km^2. The elevation within the basin varies from 752 to 2644 m. The location of the Grande River Basin delimited from Macaia gauge station (GRB-M) is shown in Figure 1.

The topography of the basin is undulated, with 57.2% of the area presenting slopes greater than 15%. Mean annual temperature of the region is about 19 °C with minimum and maximum temperatures varying from 2°C to 34°C. The climate of the region is classified as Cwa and Cwb. The former is predominant in most of the basin, and the latter in the south/southeast of the basin where is located the Mantiqueira Range, which strongly influences the temperatures and the amount of precipitation in its neighboring areas. These climate types present two seasons well characterized by mild

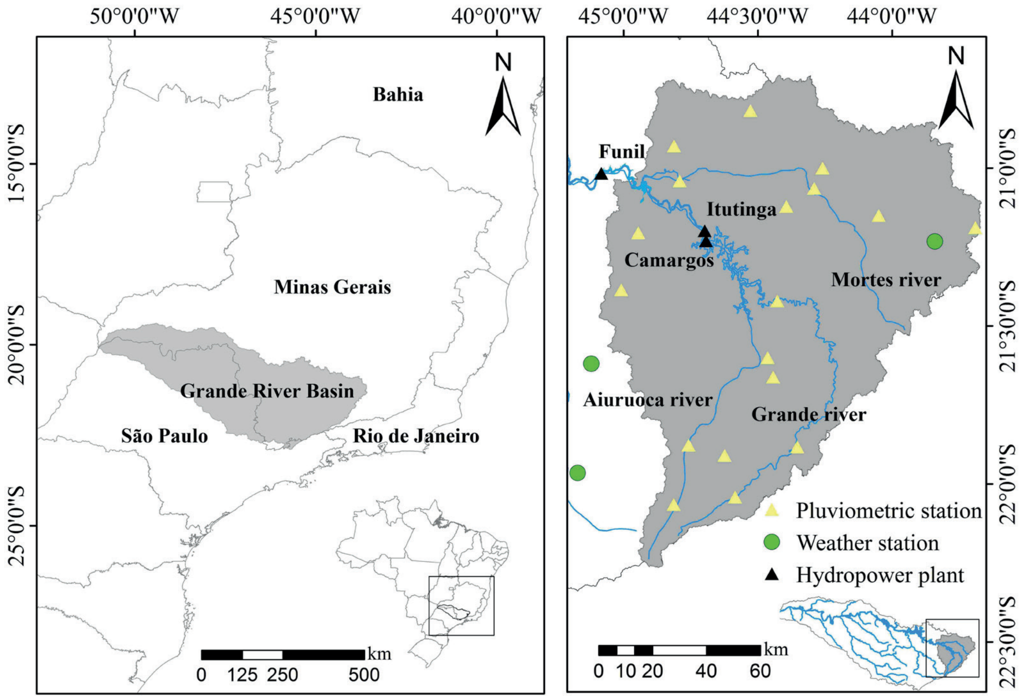

FIGURE 1 Geographical location of the Grande River Basin in Brazilian territory and the Upper Grande River Basin (GRB-M), as well as the pluviometric, fluviometric and weather stations.

and rainy summers and cool and dry winters. The mean annual rainfall is about 1500 mm, which varies from 1100 mm to 2100 mm (Oliveira et al., 2014; Viola et al., 2013; Mello et al., 2012).

SWAT inputs requirements and database

Daily maximum and minimum temperatures, solar radiation, relative humidity and wind speed were obtained from weather stations of the Brazilian National Institute of Meteorology (INMET) for Lavras, São Lourenço and Barbacena (Figure 1). In addition, daily rainfall (16 gauges) and streamflow data series were obtained from the Brazilian National Water Agency (ANA-Hidroweb). Meteorological data sets were both obtained on a daily basis from 1992 to 2001 from which five years were used for calibration (1994-1998) and three years for validation (1999-2001). The period from 1992 to 1993 was used as a warm-up period, as recommended by Daggupati et al. (2016).

The ASTER Digital Elevation Model (DEM) (NASA LP DAAC, 2015), with spatial resolution of 30 m, was used to process the topographical procedures such as generation of the drainage network and the delineation of the sub-basins of the GRB-M. The current land-use and soil maps are illustrated in Figures 2a and 2b, respectively. The current land-use map was derived from Landsat 8 images from 2013 with the aid of supervised classification through the maximum likelihood classifier. Pasture is the predominant land-use, followed by forests and agriculture, covering 70.6%, 15.8% and 10.4% of the area, respectively. The vegetation parameters used in this study were obtained from the SWAT global database.

The soil map was obtained from the Minas Gerais State Environmental Foundation (FEAM, 2010), in a scale of 1:650,000. The soil types of the GRB-M are Latosol (Oxisol), Argisol, Cambisol, Fluvic Neosol and Litholic Neosol with predominance of Cambisols (47.9%) followed by Latosols (32.6%), Litholic Neosols (9.53%), Argisols (9.2%) and Fluvic Neosols (0.7%). The soil hydro-physical properties were obtained from soil surveys and hydrological studies in the GRB-M region (Melo Neto, 2013; Mello et al., 2007; Araújo, 2006).

The SWAT model

The Soil and Water Assessment Tool (SWAT) is a large-scale model which was developed to predict the impact of land-use and management practices on water, sediment and agricultural chemical generated in large complex watersheds, land-use and management conditions over long periods of time (Neitsch et al., 2005). It is a continuous-time, long-term, distributed-parameter, physically based hydrological model that divides the watershed into sub-basins connected by a stream network. Each sub-basin is further delineated into hydrological response units (HRUs) which consist of a unique combination of land cover, slope and soil type (Srinivasan et al., 2010; Arnold et al., 1998).

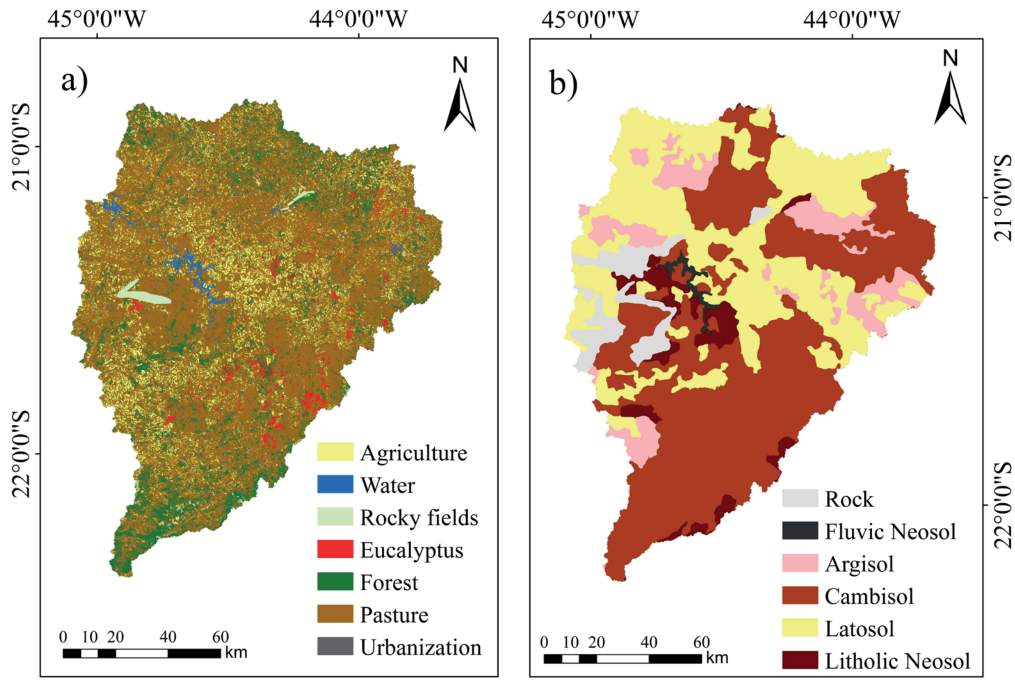

FIGURE 2 Current land-use (a) and soil (b) maps of GRB-M.

SWAT simulations are based on water balance and are achieved through hydrological routines that calculate the water cycle components such as surface and subsurface flows, evapotranspiration, infiltration, percolation and soil moisture. Equation 1 describes the water balance adopted by the SWAT model., where SW_t is the final soil water content (mm), SW_0 is the initial soil water content on day i (mm), t is the time (days), P_{day} is the amount of precipitation on day i (mm H_2O), Q_{surf} is the amount of surface runoff on day i (mm), E_a is the amount of evapotranspiration on day i (mm), w_{seep} is the amount of water entering the vadose zone from the soil profile on day i (mm), and Q_{gw} is the amount of return flow on day i (mm).

$$SW_t = SW_0 + \sum_{i=1}^{t}\left(P_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw}\right) \quad [1]$$

The model requires topography, soil, land-use and weather data as input to estimate the runoff, surface and subsurface flows, base flow, sediment, and nutrient and pesticides loadings carried out the watershed's outlet. For this study, only the components regarding the runoff process will be analyzed. A detailed description of the SWAT model is given by Neitsch et al. (2005), Arnold et al. (1998) and Srinivasan et al. (1998).

Calibration, validation and model performance evaluation

The calibration and uncertainty analyses for SWAT are carried out in SWAT-CUP, which is a program that links to SWAT's output text file sets and integrates different optimization algorithms. Among them, the Sequential Uncertainty Fitting (SUFI-2) algorithm stands out due to its capability to account for all sources of uncertainty on the parameter ranges such as uncertainty in driving variables (e.g., rainfall), conceptual model, parameters, and measured data Abbaspour et al. (2007).

This algorithm seeks to capture most of the measured data within the 95% prediction uncertainty (95PPU) calculated at the 2.5% and 97.5% levels of the cumulative distribution of an output variable obtained through Latin hypercube sampling. The degree in which all uncertainties are accounted for is quantified by a measure referred as p-factor, which is the percentage of measured data bracketed by the 95% prediction uncertainty band (95PPU). Yet, another statistic to account the uncertainties is the r-factor, which corresponds to the average thickness of the 95PPU band divided by the standard deviation of the measured data. For streamflow, simulations with good prediction of uncertainties are those with p-factor greater than 0.7 (> 70%) and r-factor around 1 (Abbaspour et al., 2004; 2007).

Automatic calibration through SUFI-2 was performed using daily streamflow time series from Macaia gauge station, at Grande River, for the period from 1994 to 1998, with a warm-up period from 1992 to 1993. The validation was performed updating the SWAT previously calibrated for the period from 1999 to 2001.

To evaluate the goodness of fit of the calibration and validation periods, the Nash-Sutcliffe Efficiency (NSE) (Nash and Sutcliffe, 1975) and the percent bias (PBIAS) were applied and are represented as follows, (2) and (3), where, Q_{obs}, Q_{sim} and Q_{mean} are the observed, simulated and mean streamflow, respectively.

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n} (Q_{obs_i} - Q_{sim_i})^2}{\sum_{i=1}^{n} (Q_{obs_i} - Q_{mean_i})^2} \right] \quad [2]$$

$$PBIAS = \left[\frac{\sum_{i=1}^{n} (Q_{obs_i} - Q_{sim_i})}{\sum_{i=1}^{n} (Q_{obs_i})} \right] \times 100 \quad [3]$$

Regarding NSE, this study adopted the recommendation proposed by Green et al. (2006), who suggest that simulations with NSE equal or greater than 0.4 are qualified as "satisfactory" considering the daily time step. The model performance regarding PBIAS was evaluated based on the recommendations of Van Liew et al. (2007) for simulations on a daily time step: $|PBIAS| <$ 10% as "very good"; 10% $< |PBIAS| <$ 15% as "good"; 15% $< |PBIAS| <$ 25% as "fair"; and $|PBIAS| >$ 25% as "unsatisfactory".

Land-use scenarios

This study investigated the impacts of land-use changes given by the interactions through four different scenarios. These scenarios were developed based on directives suggested by environmental agencies responsible for the water resources management in Minas Gerais state. These directives aim to provide management practices for a sustainable use of the natural resources considering the current and future socioeconomic features and environmental conditions of the region.

For this purpose, results and analyses published in studies like the Forest Inventory of Minas Gerais state (Carvalho and Scolforo, 2008), the Ecological-Economic Zoning of Minas Gerais State (Mello et al., 2008) and the Water Resources Directives of the Upper Grande River Basin (IGAM, 2012) were taken into account. This methodology was previously adopted by Viola et al. (2014) assessing the impacts of land-use changes on hydrology in four sub-basins of GRB headwaters, and by Beskow et al. (2013) for another watershed that drains directly to Camargos Hydropower Plant Reservoir.

Southern Minas Gerais is traditionally recognized for its dairy production and, therefore, grazing is a frequent activity. According to Viola et al. (2014), this activity has been expanded towards the Mantiqueira Range region, converting the native vegetation into extensive pastures (with low protection of soil surface). In this regard, two deforestation scenarios were considered: S_1 that considers 20% of the native vegetation in the entire basin was converted into pasture; and S_2 that considers 50%.

In addition to these scenarios, two others were structured motivated by ongoing government environmental programs such as the "Water Producer Program", which provides a payment for ecological services and is headed by the Brazilian National Water Agency (ANA – *Agência Nacional de Águas*). This program aims to reduce the soil erosion and sediment deposition in the water bodies, providing better overall water quality, increasing the quantity and promoting the regularization of natural flows in catchments mostly located in the Mantiqueira Range region by means of conservation practices, highlighting the reforestation of springs (ANA, 2012). In this context, the scenarios S_3 and S_4 considered the conversion of pastures into forests in the whole basin area by 20% and 50%, respectively.

The land-use changes were performed through the SWAT module "Land-Use Update". The "Land-Use Update" automatically adjusts the fractions of HRUs updating the current use for the new use based on the percentage given by the modeler. Consequently, the vegetative parameters, like Leaf Area Index (LAI), aerodynamic and stomatal conductance and others related to evapotranspiration are automatically changed. This approach have been used in some land use change impact studies such as Hernandes et al. (2018), Lamparter et al. (2018), Castillo et al. (2014)

Land-use change impacts on the hydrological behavior of GRB-M were quantified by comparing the simulations obtained from the land-use scenarios against the simulations obtained from the baseline (validation period). The calibrated parameters, meteorological data, soil map and landscape characteristics of the baseline simulation remained the same for the future scenarios to provide a consistent basis for comparison between the baseline and land-use change scenarios (Can et al., 2015).

Also, according to Bieger et al. (2015) and Hessel et al. (2003), when assessing land-use change impacts, all scenarios are subjected to the same input data uncertainty, therefore, it can be assumed that the relative differences in the results can be attributed to the changes influenced by the applied scenario.

Table 1 summarizes the land-use scenarios presenting the new percentages of forests and agricultural areas after changes from the current scenario (baseline). The changes were made considering the entire area of each land-use class.

TABLE 1 Land-use changes scenarios considering the area and the percentages of forests in relation to the current land-use.

Scenario	Description	ΔArea (km²)	(%)	Total class area (km²)	Δ (%)
S_1	20% - Deforestation	-486.9	12.6	1947.7	-3.1
S_2	50% - Deforestation	-1217.3	7.9	1217.3	-7.9
S_3	20% - Reforestation	2175.8	29.9	4610.5	14.1
S_4	50% - Reforestation	5439.4	51.1	7874.1	35.3

RESULTS

Model calibration and validation

The SWAT model was previously calibrated and validated before being applied to assess the impacts of land-use scenarios. To calibrate it to GRB-M on a daily time step, a set of 20 parameters regarding surface and subsurface runoff behavior were selected. The range of the parameters, their description and their respective calibrated values are represented in Table 2.

The model performance statistics showed that SWAT was able to adequately predict the daily streamflow in GRB-M, presenting a NSE of 0.72 and PBIAS of 2% for the calibration period and 0.63 and 10%, respectively, for the validation period. The hydrographs of the simulated and observed streamflow are shown in Figure 3.

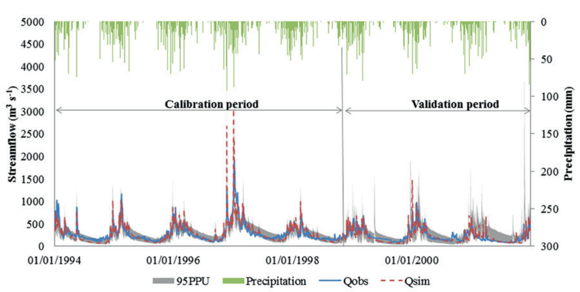

FIGURE 3 Observed and simulated daily streamflow during the calibration and validation periods by SWAT and respective 95PPU band for GRB-M.

Impacts of projected land-use change scenarios on streamflow

In order to assess the impacts of land-use changes on hydrology, the average streamflow data set was divided into summer and winter seasonal flows. This assessment is essential since it indicates the variations of the streamflow during the winter and summer periods, when the low and peak flows, respectively, are pronounced.

Table 3 shows the variations on the mean summer and winter streamflows compared to the baseline (1999-2001). It also shows the mean observed streamflow for the period 1999-2001. The average summer streamflow was calculated for the period between December and March, whereas the winter ones were calculated from June to September.

Impacts of projected land-use change scenarios on the water balance

Table 4 shows the deviations of the mean annual runoff (R), baseflow (BF), surface runoff (SR), evapotranspiration (ET) and precipitation (P) and the hydrological indicators (BF/R; SR/R) under land-use scenarios in relation to the baseline.

TABLE 2 Parameters used to calibrate SWAT for GRB-M and their respective initial ranges and final calibrated values. The prefixes "v", "r" and "a" correspond to the operations "replace", "relative" and "add", respectively (refer to Abbaspour et al., 2004).

Parameter	Parameter description	Initial range Min	Initial range Max	Final value
v_ESCO	Soil evaporation compensation coefficient	0.5	0.95	0.812
r_CN2	Initial SCS runoff curve number for moisture condition II	-0.1	0.1	-0.011
v_ALPHA_BF	The baseflow recession constant	0.005	0.015	0.009
a_GW_DELAY (days)	Groundwater delay time	-30	60	-9.75
a_GWQMN (mm)	Threshold depth of water in the shallow aquifer required for return flow to occur	-1000	1000	906
v_CANMX (mm)	Maximum canopy storage	0	30	14.67
v_CH_K2 (mm·h⁻¹)	Effective hydraulic conductivity in main channel	0	10	8.849
v_CH_N2	Manning's "n" value for the main channel	-0.01	0.2	0.15
v_EPCO	Plant uptake compensation factor	0.01	1	0.951
v_GW_REVAP	Groundwater "revap" coefficient	0.02	0.2	0.043
a_REVAPMN (mm)	Threshold depth of water in the shallow aquifer for "revap" or percolation to the deep aquifer to occur	-1000	1000	610
r_SOL_AWC (mm·mm⁻¹)	Soil available water capacity	-0.05	0.05	-0.024
r_SOL_K (mm·h⁻¹)	Saturated hydraulic conductivity	-0.05	0.05	-0.029
v_SURLAG (days)	Surface runoff lag coefficient	0.01	24	1.713
v_CH_N1	Manning's "n" value for tributary channels	0.01	0.2	0.199
v_CH_K1 (mm·h⁻¹)	Effective hydraulic conductivity in tributary channels	0	5	1.705
v_SLSOIL (m)	Slope length for lateral subsurface flow	0	150	13.823
v_LAT_TTIME (days)	Lateral flow travel time	0	150	11.25
r_HRU_SLP (m·m⁻¹)	Average slope steepness	-0.25	0.25	-0.093
r_SLSUBBSN	Average slope length	-0.25	0.25	0.142

TABLE 3 Annual mean, summer and winter mean streamflow variations caused by the land-use scenarios in relation to the baseline, considering the 1999-2001 period.

Streamflow ($m^3 \cdot s^{-1}$)	Observation ($m^3 \cdot s^{-1}$)	Qbaseline ($m^3 \cdot s^{-1}$)	S_1	S_2	S_3	S_4
			$\Delta Q (m^3 \cdot s^{-1})$			
Q_{mean}	220.8	198.4	0.5	1.2	-1.7	-3.9
Q_{summer}	293.8	264.2	1.5	3.9	-5.5	-12.1
Q_{winter}	148	133	-0.2	-0.6	0.5	1.8
Q_{max}	757.1	938.3	1.6	1.9	-4.1	-11.4
Q_{min}	88.1	69	-0.02	-0.1	-0.12	0.13

TABLE 4 Hydrological indicators and water balance components and their deviation from the baseline simulation.

Components	Observed (mm)	Baseline (mm)	S_1	S_2	S_3	S_4
			$\Delta (m \cdot m)$			
R	428.7	403.9	1.4	1.9	-0.9	-2.8
BF	324.6	279	-0.6	-4.6	4.3	6.9
BF/R	0.76	0.69	0.69	0.68	0.7	0.71
SR	104.1	124.9	1.9	7	-5.2	-9.7
SR/R	0.24	0.31	0.31	0.32	0.30	0.29
ET	-	763.4	-1.1	-2.9	4.5	11.3
P	1402.1	-	-	-	-	-

DISCUSSION

Model calibration and validation

From Figure 3 it is possible to observe that both calibration and validation periods presented a good agreement with the observed data, especially for the prediction of the low flows. On the other hand, there was some overestimation of the peak flows, especially in the summer of 1996-1997. However, considering the model performance criteria adopted in this study the results can be framed as "satisfactory" and "very good" based on the NSE and PBIAS statistics, respectively. Regarding the uncertainty prediction measured by the p-factor and r-factor the validation period presented greater degree of uncertainty in comparison with the calibration period.

According to Moriasi et al. (2007), the NSE is very sensitive to extreme high flows, and, therefore, an overestimation of the peak flows can influence the NSE statistics. PBIAS statistic measures the average bias of the simulated data, thus, positive values indicate underestimation and negative values, overestimation of the observed data. The results showed that the simulated streamflow has presented the same trend for both calibration and validation periods, with a slight better performance during calibration.

Impacts of projected land-use change scenarios on streamflow

The results showed that the mean streamflow increased under the deforestation scenarios of 0.5 and 1.2 $m^3 \cdot s^{-1}$ for S_1 and S_2, respectively, and decreased in the reforestation scenarios of 1.7 and 3.9 $m^3 \cdot s^{-1}$ for S_3 and S_4, respectively. Additionally, there was a reduction of the mean winter flows of 0.2 and 0.6 $m^3 \cdot s^{-1}$ for S_1 and S_2, respectively, and an increase in the mean summer flows of 1.5 and 3.9 $m^3 \cdot s^{-1}$. These results indicate a reduction in the low flows during the winter and an increase of the peak flows during the summer, which is corroborated by the increase in the maximum streamflow of 1.6 and 1.9 $m^3 \cdot s^{-1}$ for S_1 and S_2 scenarios, respectively. According to Viola et al. (2014), when forests are removed, the infiltration and SWC are both reduced, which leads to an increase in the surface runoff, and therefore, increasing the peak flows and the total runoff. The increase in peak flow under deforestation scenarios is also reported by Lamparter et al. (2018) and dos Santos et al. (2018).

Under the reforestation scenarios, the mean winter flows would have an increase of 0.5 and 1.8 m^3 s^{-1} for S_3 and S_4, respectively, thus, indicating increases of the low flows and in the ground water recharge. On the other hand, reductions of the summer flows of 5.5 and -12.1 m^3 s^{-1} and in the maximum streamflows of 4.1 and 11.4 m^3 s^{-1}, were also observed for S_3 and S_4, respectively, indicating an attenuation of the peak flows from December to March.

According to Lamparter et al. (2018), Wiekenkamp et al (2016) and Viola et al. (2014), the reforestation in grasslands areas leads to a regulation of the low flows and a reduction of the peak flows, since it increases the infiltration capacity and the effective root zone, thus, increasing SWC. It also increases the rainfall interception and the evapotranspiration due to an increase of the land cover area. In addition, the soil erosion risks are reduced, since the reforestation provides protection for the soil.

Impacts of projected land-use change scenarios on the water balance

According to the results presented in Table 4, in general, the signal of the water balance components simulated based on the land-use change scenarios presented an agreement with both experimental and simulation results presented by Lamparter et al. (2018), dos Santos et al. (2018), da Silva et al. (2018), Carvalho-Santos et al. (2016), Bieger et al. (2015), Can et al. (2015), Viola et al. (2014), Baker and Miller (2013), Sahin and Hall (1996), Bruijnzeel (1990), among others. However, as discussed by Pereira et al. (2016), with respect to the changes in water quantity there has been no consensus. It is noted an increase in the mean annual runoff under the deforestation scenarios S_1 and S_2 of 1.4 and 1.9 mm, respectively. These scenarios also showed a decrease in the base flow of 0.6 and 4.6 mm and an increase in the surface runoff of 1.9 and 7 mm, respectively, corroborating with the assumptions previously discussed.

Alternatively, regarding the reforestation scenarios, the water balance components showed the same behavior as the one assessed previously. These scenarios indicate an increase in the baseflow of 4.3 and 6.9 mm and a decrease in the runoff of 0.9 and 2.8 mm for S_3 and S_4, respectively. However, the results obtained in this study with respect to the annual runoff were below the ones cited above, which report that an increase of 10% in forested areas may lead to a decrease in the annual runoff of 10 mm. The contribution of the baseflow in relation to the runoff (BF/R) would increase from 69%, under baseline conditions, to 71 and 72% under S_3 and S_4, respectively. Beyond this, these scenarios showed a reduction of the surface runoff of 5.2 and 9.7 mm, respectively, for S_3 and S_4.

These results can be due to an increase in the effective root zone, since forests have deeper roots than grasslands, which leads to an increase of SWC, therefore decreasing the surface runoff. Furthermore, the water consumption by the trees increases, which also contributes for this reduction (Viola et al., 2014). This is corroborated by the behavior of the evapotranspiration under the scenarios S_3 and S_4, which increased in 4.5 and 11.3 mm, respectively, indicating an increase in water consumption by the trees,

In general terms, the reforestation scenarios (S_3 and S_4) generates a positive impact over the region by increasing the ground water contribution and attenuating the peak flows, making the basin more capable to sustain the baseflow due to greater capacity for natural regularization of the streamflows. On the other hand, the deforestation scenarios (S_1 and S_2) might generate negative impacts within GRB-M not only in the hydrological cycle - reducing the water availability and increasing soil erosion and flood risks - but in socioeconomic development, given its importance in agricultural production and hydropower generation in the regional scale.

CONCLUSIONS

The SWAT model was able to predict adequately the hydrological processes in GRB-M according to the model performance criteria adopted in this study, therefore it was able to reproduce the changes on the hydrological regime based on different land-use scenarios. In general, the deforestation scenarios (S_1 and S_2) would tend to present an increase in the runoff and decrease in the baseflow. Consequently, this condition may lead to an increase in the maximum streamflows and in surface runoff. Alternatively, the results based on the reforestation scenarios (S_3 and S_4) presented a decrease in runoff and an increase in the baseflow.

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