Simulation of land use scenarios in the Camboriú River Basin using the SWAT model

Simulação de cenários de uso e ocupação das terras na bacia hidrográfica do Rio Camboriú utilizando o modelo SWAT

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ABSTRACT

Changes in the Earth's landscape have been the focus of much environmental research. In this context, hydrological models stand out as tools for several assessments. This study aimed to use the Soil and Water Assessment Tool (SWAT) hydrological model to simulate the impact of changes in land use in the Camboriú River Watershed in the years 1957, 1978, and 2012. The results indicated that the SWAT model was efficient in simulating water flow and sediment transport processes. Thus, it was possible to evaluate the impact of different land use scenarios on water and sediment yield in the catchment. The changes in land use caused significant changes in the hydro-sedimentological dynamic. Regarding flow, the effects of land use changes were more pronounced at both ends of the curve representing duration of flow. The worst scenario was identified for the year 2012, which saw the highest peak discharges during flood events and lowest flows during the dry season. Concerning soil erosion, the highest values were identified for sub-basins that were predominantly covered by rice paddies and pastures; this was attributed mainly to surface runoff and changes in land use (represented by C-USLE). Overall, the Camboriú River Basin did not experience severe soil erosion issues; however, it was found that changes in land use related to soil and climate characteristics may increase soil degradation, especially in years with high precipitation levels.

Keywords: Land use; Basin; Hydrologic scenarios.

RESUMO

As mudanças de paisagem têm sido foco de pesquisas na área ambiental. Nesse contexto, os modelos hidrológicos se destacam como ferramentas para diferentes análises. Nesse trabalho, o objetivo foi utilizar o modelo hidrológico SWAT para simular os impactos das alterações no uso e ocupação das terras da bacia hidrográfica do Rio Camboriú (BHRC) entre os anos de 1957, 1978 e 2012. Os resultados indicaram que SWAT foi eficiente para simulação da vazão e da perda de solo possibilitando a quantificação dos impactos a partir da simulação de cenários. As mudanças na cobertura do solo acarretaram alterações significativas no regime hidrossedimentológico. Para a vazão, os impactos foram maiores nos extremos da curva de permanência. O cenário 2012 se destacou negativamente por apresentar as maiores vazões de pico e as menores vazões em período de estiagem. Para a perda de solo, os maiores valores foram identificados nas sub-bacias com uso predominante para rizicultura e pastagens, o que foi atribuído, fundamentalmente, a alterações da taxa de escoamento superficial e aos fatores relacionados ao uso, manejo do solo e práticas conservacionistas. De maneira geral, a BHRC não apresentou problemas severos de perda de solo, entretanto, as mudanças na paisagem associadas as características edafoclimáticas podem favorecer a degradação do solo, principalmente em anos com elevados volumes de precipitação.

Palavras-chave: Uso e ocupação das terras; Bacia hidrográfica; Cenários hidrológicos.

INTRODUCTION

The replacement of native vegetation by agricultural crops can produce drastic changes in the structure and fertility of soil, usually culminating in environmental degradation. This degradation can occur when inadequate crop management techniques are used or when areas unfit for agriculture are farmed.

In these cases, the gradual loss of the soil's productive capacity and the degradation of water quality by sediment and various pollutants have been identified.

Studies that aim to quantify the changes in land use and occupation and their impact on river basins have been carried out in several regions of Brazil (MACHADO et al., 2003; LELIS et al., 2012; SILVA et al., 2011; BLAINSKI et al., 2014) and around the world (PIKOUNIS et al., 2003; BEHERA; PANDA, 2006; BRACMORT et al., 2006; ARABI et al., 2006; GHAFFARI et al., 2010; BAKER; MILLER, 2013; CAN et al., 2015). In these studies, hydrological models have been widely used because they enable the simulation of hypothetical scenarios and the quantification of potential impacts resulting from changes in land use and human occupation on the hydro-sedimentological dynamic.

Hydro-sedimentological modeling refers to the representation of the natural processes that determine the flow of water and sediments in a hydrographic basin. Such modeling is based on a set of mathematical equations capable of describing the complexity of the natural phenomena (STEYAERT, 1993; MAIDMENT, 1993; TUCCI, 2005).

Computational advances and the coupling of hydrological models to geographic information systems (GIS) have enabled the representation of temporal and spatial variability of edaphic, climatic, topographic, land use and occupation, and crop management parameters; this in turn makes it possible to evaluate the changes in these variables and their impact on river basins.

The Soil and Water Assessment Tool (SWAT) is one of the models of hydro-sedimentology and water quality employed in studies of hydrographic basins. This is a physical model developed by the Agricultural Research Service and Texas A & M University, the main objective of which is to represent the hydro-sedimentological dynamic and water quality in monitored hydrographic basins (NEITSCH et al., 2011; ARNOLD et al., 2012a).

One characteristic of the SWAT model is its ability to describe different physical processes sequentially, with different temporal and spatial scales. This makes it possible to quantify the impact of changes in land use and occupation on surface and sub-surface runoff, erosion and deposition of sediments, water quality, and pollutant loads (REUNGSANG et al., 2009).

In the SWAT model, complex natural phenomena can be simulated using simplified equations. To achieve a satisfactory representation of the water flow and sediments in watersheds, a great quantity of information is necessary; numerous authors have identified this issue as the main limiting factor in the use of this tool (e.g., BEVEN, 2001; BRESSIANI et al., 2015).

In addition, an indispensable step in hydrological modeling is the calibration and validation of the models in the observed time frames. The calibration process is complex, requiring long, continuous historical sequences, and detailing the physical characteristics of hydrographic basins (GREEN; VANGRIENSVEN, 2008; BALTOKOSKI et al., 2010; ARNOLD et al., 2012b).

Thus, despite computational advances and the increasing use of models coupled with GIS, modeling studies of the Brazilian watershed are still scarce and many of the published works do not describe the protocols used at this stage. Although labor-intensive, modeling offers a number of advantages in determining the effects of human activity on watersheds even before they occur. It provides the information necessary to ensure identification of the origin, nature, and magnitude of these effects (GRIGG, 1996; BOURAOUI et al., 1997; BONUMÁ et al., 2015).

In this context, the objective of this study was to use the SWAT model to simulate land use and occupation scenarios in the Camboriú river basin (CRB), Santa Catarina, in order to identify changes in water flow and loss of soil caused by changes to the landscape that occurred between 1957 and 2012.

Two aspects of this work should be highlighted. The CRB has undergone intense urbanization in recent decades; the changes that occurred were identified with remote sensing surveys carried out over more than half a century. In addition, recent planimetric surveys have resulted in high spatial resolution, allowing the application of detailed hydrological models to this river basin.

METHODOLOGY

Study area

The study area has been monitored by the Agricultural Research and Rural Extension Company of Santa Catarina (Epagri) since 2012. During this period, a set of data collection platforms (DCPs) were installed, to enable monitoring the precipitation, temperature, relative and humidity of the air, speed, and direction of the wind, level of rivers, flow, and total suspended solids (TSS) through the network of channels that comprise the river basin. See Figure 1.

This catchment area is about 195 km² and is located in the municipalities of Camboriú and Balneário Camboriú, in the state of Santa Catarina. According to Köppen classification, the climate of this region is classified as humid subtropical mesothermal, with an average temperature below 18°C in the coldest month and above 22°C in the warmest month, with hot summers and infrequent frosts. The rainfall can vary from 1,430 mm to 1,908 mm and there is a trend of rainfall concentration in the summer months; however, there is no defined dry season (PANDOLFO et al., 2002).

The following land use/land cover classes were identified from 2012 orthophotos: forests at an advanced stage of regeneration (62.8% of the total catchment area), pasture (17%), urban areas (8.2%), irrigated rice fields (5.7%), reforestation (2.5%), rural roads (1.7%), exposed soil (1.2%), water bodies (0.5%), and annual crops (0.4%).

The predominant soil types of the CRB are the *Cambisolos*, the *Argisolos* and the *Gleisolos*, occupying, respectively, 48.7%, 16.5%, and 12.7% of the total area of the river basin. In addition, *Neosolos* (10.9%), *Espodosolos* (8.5%), and other groupings (2.7%) were mapped (EMBRAPA, 2013). Soil was mapped using samples collected manually along the basin. From the description of the
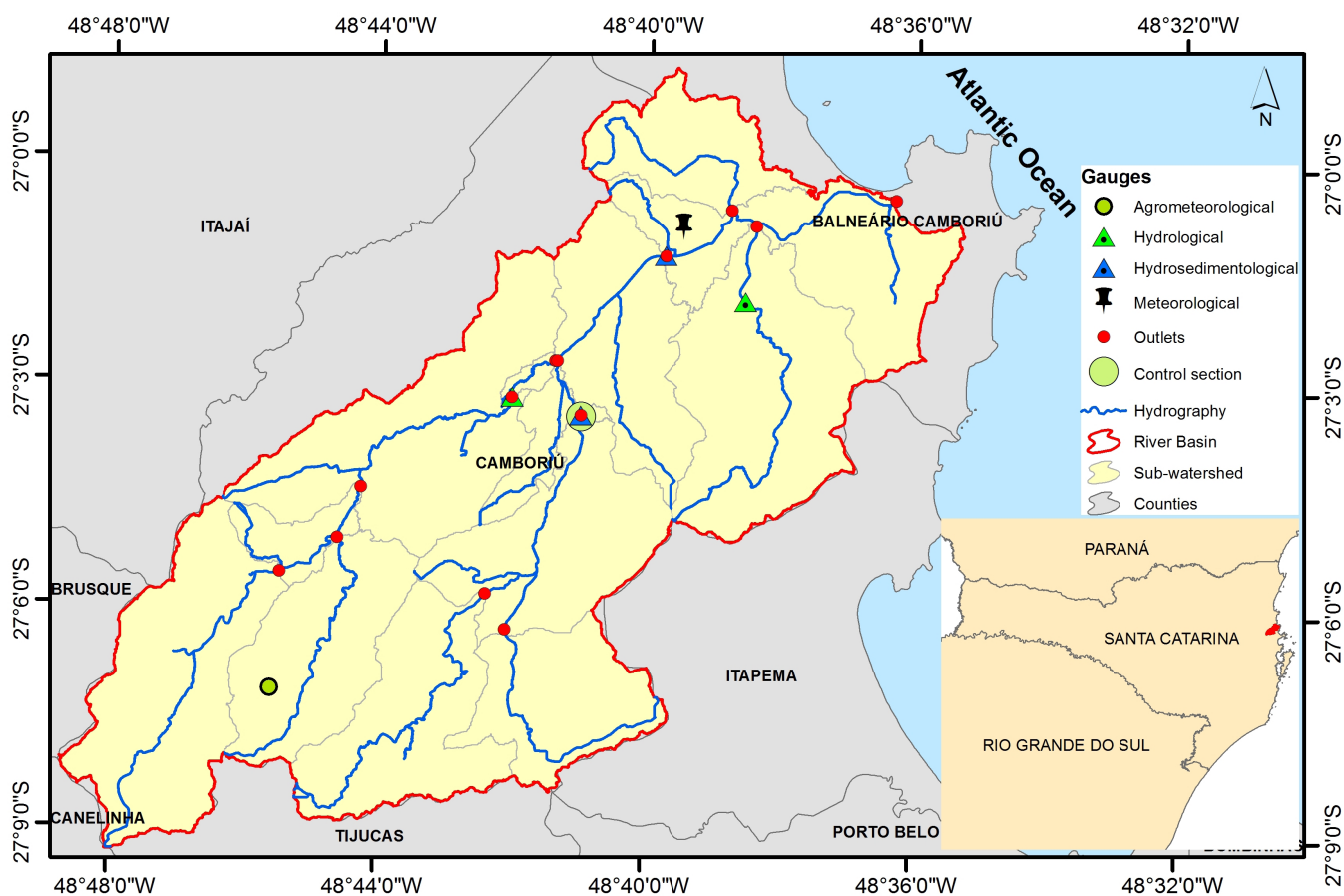
Figure 1. Location of the Camboriú River Basin, outlets monitoring points, sub-watershed and data collection platforms.

profiles and the results of the physical-chemical analysis, the characteristics for each polygon were determined, based on the methodology described in EMBRAPA (2013).

The topography was characterized based on the digital terrain model (DTM). These data were obtained from the aerial survey of Santa Catarina conducted by the Secretariat of Sustainable Development (SDS/SC) in 2010; the model was adjusted for a spatial resolution of 3 m. The basin was divided into 5 slope classes identified from the DTM and adapted to the model calculation according to the following classification: 0 to 6%; 6 to 20%; 20-35%; 35-48, and > 48%.

The SWAT model

SWAT is a hydrology model that has its physical foundation in the characteristics of river basins. It is a continuous time model and capable of simulating long periods (ARNOLD et al., 2012a). According to the authors, the model was developed with a command structure that is able to partition the area into homogeneous units named hydrologic response units (HRUs). Each HRU has climatic, edaphic, topographic, vegetative, and soil management components, making it possible to simulate flow, sediments, and nutrients at different levels.

The hydrological component of the model includes subroutines for determining runoff, percolation, subsurface lateral flow, shallow aquifer return flow, and evapotranspiration.

Potential evapotranspiration was estimated using the Penman-Monteith method (ALLEN et al., 1989). The hydrological cycle simulated by SWAT is based on Equation 1:

$$SW_t = SW_0 + \sum_{i=1}^{t} \left(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw} \right) \qquad (1)$$

where SW_t is final soil water content (mm); SW_0 is initial soil water content on day i (mm); t is time (days); R_{day} is amount of precipitation on day i (mm); Q_{surf} is amount of surface runoff on day i (mm); E_a is evapotranspiration on day i (mm); W_{seep} is the amount of water entering the vadose zone from the soil profiles on day i (mm); Q_{gw} is the amount of return flow on day i (mm).

The peak flow was estimated by the modified rational formula. The surface runoff was calculated by the Soil Conservation Service curve number method (SCS-CN) (NEITSCH et al., 2011). The CN values defined for each land use/land cover class are presented in Table 1. The erosion caused by rainfall was calculated with the Modified Universal Soil Loss Equation (MUSLE (WILLIAMS, 1975). The MUSLE equation enables simulating erosion from surface runoff. Equation 2 is as shown below:

$$Sed = 11.8 \cdot (Q_{surf} \cdot q_{peak} \cdot area_{hru})^{0.56} \cdot K \cdot C \cdot P \cdot LS \cdot CFRG \qquad (2)$$

where Sed is Sediment yield (t ha^{-1}); Q_{surf} is Surface runoff volume (mm ha^{-1}); q_{peak} is Peak runoff rate (m^3 s^{-1}); $area_{hru}$ is Area of the HRU (ha); K is USLE soil erodibility factor; C is USLE cover

and management factor; *P* is USLE support practice factor; *LS* is Topographic factor; *CFRG* is Coarse fragment factor.

The values selected for factor C (USLE cover and management factor) and factor P (USLE support practice factor) to estimate the erosion are shown in Table 1.

The flow of solids through the channel network is based on deposition processes and degradation. The deposition within the channel to the exudate of the basin was determined from the deposition velocity of the sediment particles (MELO NETO et al., 2014). The sedimentation velocity was calculated from Stokes law and the sediment degradation in the canal was based on Bagnold's concept of flow power of Bagnold (1977).

Meteorological and hydro-sedimentological data

Meteorological monitoring was performed from five DCPs installed in the study area (Figure 1). The following parameters were collected hourly, for a period of three years (from 2012 to 2015): temperature and relative air humidity, wind speed, precipitation, and solar radiation. To expand the series of climate data, a DCP installed from the river basin was used to extend the data set between the years 1981 and 2015.

TSS was monitored using multi-parametric probes coupled to hydro-sedimentological DCPs (Figure 1). The river level was measured in three sub-basins and the flow was determined in the control section with the larger time frame (Figure 1). The key curve was established through the collection of hydrometric measurements, according to Equation 3:

$$Q = 0.0207 \cdot (N_1 - N_0)^{1.284} \tag{3}$$

where Q is water flow (m³ s⁻¹); N_1 is water level in the control section; N_0 is water level in the monitoring section.

The amount of TSS was determined indirectly, from the correlation between nephelometric turbidity units (NTU) and TSS, collected between 2012 and 2015. The turbidity values were converted to TSS using Equation 4. Finally, the stream loads were determined by the product of the TSS content and the water flow at the time.

$$TSS = (0.8695 \cdot TURB) + 66.849 \tag{4}$$

where TSS is total suspended solids (mg L⁻¹); TURB is turbidity (NTU).

Calibration and validation of the hydrological model

The SWAT model was calibrated using the SWAT-CUP automated software. The Sequential Uncertainty Fitting algorithm (SUFI-2) was used for calibration and sensibility analysis.

This algorithm relies on user-defined simulations to map uncertainties on the parameters and try to capture the measured data with a prediction uncertainty rate of 95% (95PPU), using Latin hypercube sampling to calculate the levels of the accumulative distribution of an output variable. (ABBASPOUR et al., 2007).

Most of parameters selected in the calibration process are uncertainties in terms of the parameters themselves, inputs, or conceptual models that are difficult to measure in the field. In addition, in Brazil there is little information available about these parameters. Thus, the range of values used in the calibration process was defined based on similar research (SANTHI et al., 2001; ANDRADE, 2011; ARNOLD et al., 2012b; BRIGHENTI; BONUMÁ; CHAFFE, 2016) and adjusted to represent natural processes from monitored hydro-sedimentological data.

The parameters, ranges, and values fitted for the calibration process are shown in Table 2.

For the calibration, daily flow and TSS data were collected between 1 Jan 2014 and 31 Dec 2014; validation was performed between 1 Jan 2015 and 31 Dec 2015. These periods were selected based on the series of monitoring data available for comparison with the data simulated by the model.

Evaluation criteria

To evaluate SWAT performance, the following precision statistics were used: Nash-Sutcliffe coefficient (NSE), Equation 5, and the residual mass coefficient (*BIAS*), described in Equation 6.

The perfect correlation between simulated and observed data is expressed as *NSE* = 1. Values of *NSE* < 0 demonstrate that using the mean of the observed values is better than the simulated results (BRIGHENTI; BONUMÁ; CHAFFE, 2016).

Table 1. Parameters describing the hydro-sedimentological processes of the river basin in each soil class.

Land Use/ Land Cover	CN*				USLE**	
	a	b	c	d	C	P
Irrigated rice fields	62	74	82	85	0.05	0.5
Annual crops	67	77	83	87	0.15	0.3
Dune	39	61	74	80	1	1
Forest	26	55	70	77	0.01	0.5
Forest plantation	30	60	72	82	0.03	0.5
Pasture	47	67	81	88	0.05	0.5
Bare soil	70	80	87	90	1	1
Urban area	77	85	90	92	1	1

Source: *Tucci (1993). **Arnold et al. (2012). (CN) curve number; (a) sandy soils, low clay content; (b) sandy soils, with a clay content > group A and < 15%; (c) soil with a clay content between 20 and 30%; (d) clayey soils with > 30% clay content and low infiltration capacity; (C) USLE cover and management factor; (P) USLE P support practice factor.

$$NSE = \left[\frac{\sum_{i=1}^{n} \left(V_i^{obs} - V_i^{sim} \right)^2}{\sum_{i=1}^{n} \left(V_i^{obs} - V^{mean} \right)^2} \right] \qquad (5)$$

where NSE is Nash-Sutcliffe efficiency coefficient; n is total number of observations; V_i^{OBS} is observed value; V_i^{SIM} is simulated value; V^{mean} is Mean of observed data in the period.

$$BIAS = \left[\frac{\sum_{i=1}^{n} V_i^{sim} - \sum_{i=1}^{n} V_i^{obs}}{\sum_{i=1}^{n} V_i^{sim}} \right] \qquad (6)$$

where $BIAS$ is deviation; V_i^{SIM} is simulated value; V_i^{OBS} is observed value; n is total number of observations.

The trend between simulated and measured values is expressed by the BIAS coefficient. BIAS = 0% indicates a perfect relationship between the observed and the simulated data, positive values indicate underestimation, and negative values indicate overestimation of the simulated values.

To classify SWAT performance, the values defined by Santhi et al. (2001) were used: very good: $NSE \geq 0.65$; good: $0.65 > NSE \geq 0.54$ and fair: $0.54 > NSE \geq 0.50$.

For $BIAS$, the scale proposed by Liew et al. (2007) was used: very good: $|BIAS| \leq 10\%$; good: $10\% < |BIAS| \leq 15\%$; fair: $15\% < |BIAS| \leq 25\%$ and unsatisfactory: $|BIAS| > 25\%$.

Land use and occupation scenarios

Three scenarios of land use and occupation were simulated. The scenarios were defined with differing input for the land use and occupation information. To create the layers, orthophotos corresponding to the years 2012, 1978, and 1957 were used, and renamed respectively to scenarios 1, 2, and 3 (Figure 2).

In the simulations, the parameters were adjusted in the model calibration (Table 2) using how baseline the scenario corresponding to the 2012. The same meteorological data, soil layer data, and digital elevation model were maintained for all three models.

The effect of changes in land use and occupation on the hydro-sedimentological dynamic was evaluated at the monitoring point at which water is taken for urban water supply - Water Intake (Figure 2) and in the outlets of the watershed. The three
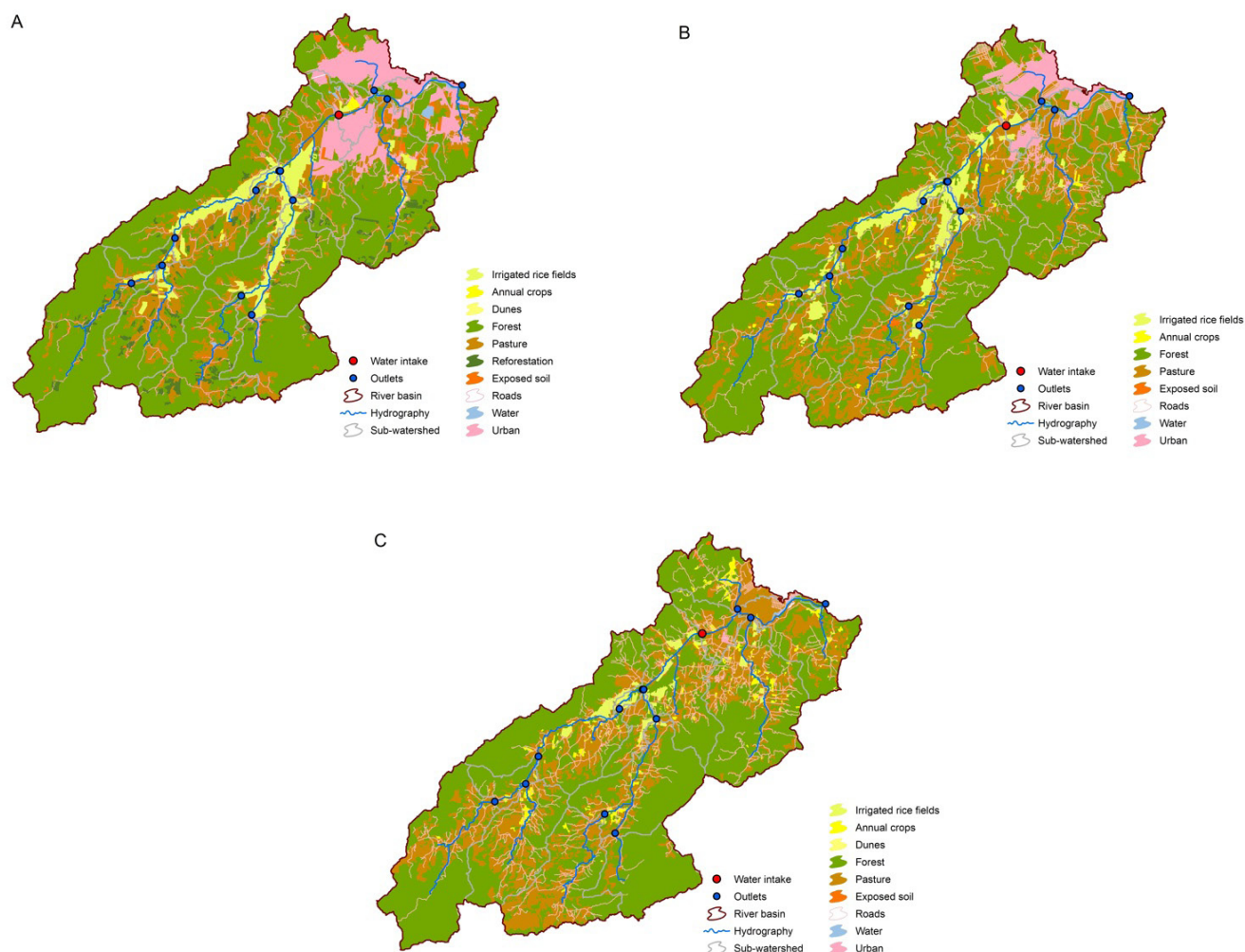

Figure 2. Land use and land cover, (A) 2012; (B) 1978; and (C) 1957.

Table 2. Parameters, ranges, and fitted values in the process for the SWAT calibration model.

	Parameter	Fitted Value	Range
1	Lat_Time	42	0 to 180
2	Esco	0.90	0 to 1
3	Gwqmin	1,000	0 to 5,000
4	Revapmn	1,000	0 to 1,000
5	Alpha_BF	0.60	0 to 1
6	Gw_delay	0.65	0 to 500

Lat_Time: lateral flow travel time (day); Esco: soil evaporation compensation factor; Gwqmin: threshold depth of water in the shallow aquifer required for return flow to occur (mm); Revapmn: threshold depth of water in the shallow aquifer for "revap" or percolation to the deep aquifer to occur (mm); Alpha_Bf: base flow alpha factor (1/days); Gw_delay: groundwater delay (days).

scenarios were compared in order to identify patterns of change in the simulated variables.

The period from 2000 to 2005 was used to model simulation warm-up. This period is important for reducing systematic errors (ANDRADE, 2011), in that it guarantees that all components of water balance and sediment reached a state of equilibrium. Finally, the period between 2006 and 2015 was used for the analysis of results.

RESULTS AND DISCUSSION

Calibration and validation of the hydrological model

The results of flow (m³ s⁻¹) and TSS (t dia⁻¹), as simulated by SWAT, were compared with observed data (Figures 3 and 4). For the flow, the NSE was 0.66 in the calibration and 0.89 in the daily validation (Figure 3). The results show a better results of the model in the validation (2015), possibly influenced by the discrepancy between measured and simulated data in the calibration stage (2014) between March and mid-April (Figure 3). Possible causes of these results may be any of the following:

- Overestimation of precipitation measurements would have favored the overestimation of the simulated flow rate;
- Underestimation of water level measurements; this would have contributed to the underestimation of the measured flow;
- External factors – during this period, water was withdrawn for irrigation of the rice crop

BIAS indicates a small deviation between observed and simulated data, including underestimations of the flow by 3% in the calibration and 14% in the validation.

According to the values of *NSE* and the scale developed by Santhi et al. (2001), the SWAT model provides highly accurate flow estimations. In addition, the BIAS values indicate a performance level of "Good" in the calibration and "Very Good" in the validation (LIEW et al., 2007). Thus, the model was classified as suitable for the simulation of land use scenarios in the CRB.

Figure 4 shows the comparison between measured and simulated TSS transported in the control section during execution
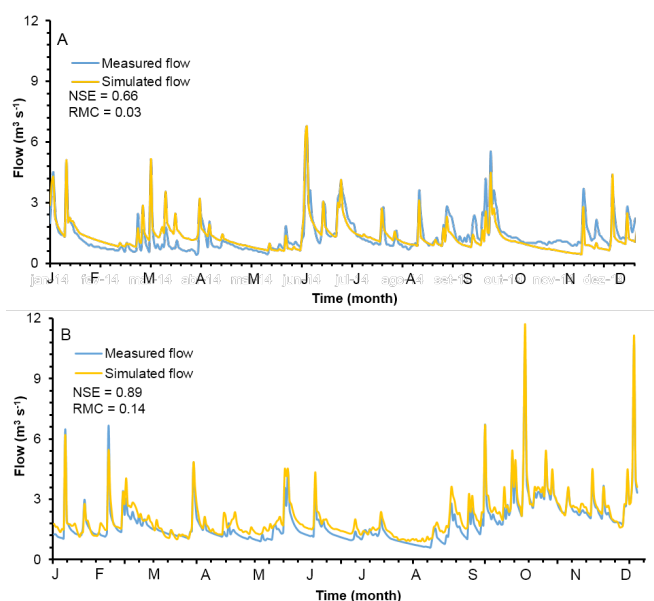

Figure 3. Measured and simulated hydrograph for CRB on calibration data set (A) and validation (B), in the control watershed.
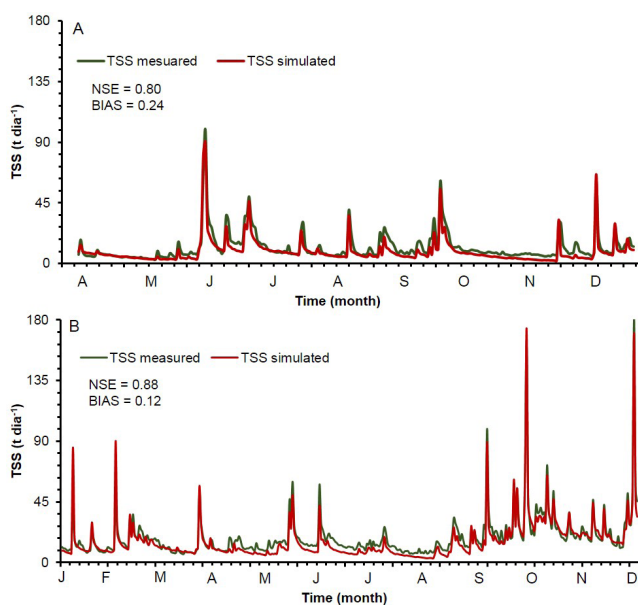

Figure 4. Measured and simulated sediment graph for CRB in the calibration period (A) and validation (B) in the control watershed.

of the daily step. The sediment graph indicates strong adhesion between the measured and the simulated data. NSE was 0.80 in the calibration period (Figure 4), which is a strong result for NSE (according to SANTHI et al., 2001). The BIAS result of 0.24 indicates an underestimation of the simulated variable (LIEW et al., 2007) in calibration. For the validation period, NSE was 0.88 and BIAS was 0.12, indicating better performance in estimating the amount of TSS (Figure 4).

It is not always possible to identify the causes of variation between simulated and modeled data, but these results support the hypothesis regarding the overestimation of the precipitation and/or

underestimation of the measured variable, as previously indicated for the flow variable. Despite the variation between simulated and observed data, the statistics allow classifying the SWAT as very good, with a tendency to underestimate the simulated variable by 12%; this is satisfactory in studies using daily step calibration.

Land use land cover simulation scenarios

The main scientific contribution of this study is to demonstrate the impact of land use/land cover changes on the water and sedimentological process in the Camboriú river basin. Table 3 shows the areas occupied with each class of activity for the simulated scenarios. The principal modifications were the urban class, pasture, and irrigated rice fields; there were significant increases in areas of urban use and rice fields, and some reduction of pasture between 1957 and 2012.

Flow simulation

The results of the land use/land cover scenarios were compared to each other to identify changes in hydrological behavior.

For this, the flow permanence curves were initially generated for the three scenarios. This approach enables visualizing the behavior of the variable from the cumulative frequency of data over time. Figure 5 shows the average simulated daily flow (m^3 s^{-1}) over a 10-year period (2006–2015), classified according to probability of occurrence. The water flow associated with 100% probability is overcome in two scenarios, while discharge corresponding to a probability of 0% was not exceeded during the same period.

The results of water flow from the simulated scenarios were classified into five ranges: *base flow*, *base flow in dry conditions*, *intermediate flow*, *wet condition flow* and *high flow* (Figure 5). This approach enables identifying the range that is most affected by the modifications in the land use/land cover scenarios. The *base flow* and *base flow in dry conditions* ranges (exceedance probability > 60%) were most heavily affected, while the *high flow* range (exceedance probability < 10%) was the second most heavily affected.

Comparing the results in the *high flow* range, the highest values were recorded for the 2012 scenario, followed by the 1978 and 1957 scenarios. Selecting the flow with an exceedance probability of less than 10% (Q$_{10\%}$), the 2012 scenario shows a flow 16% higher than the Q$_{10}$% recorded in the 1957 scenario.

In the *base flow* and *dry base flow* ranges, the 2012 scenario shows extreme conditions, followed by 1978 and 1957.

Several authors associate the alteration of landscape to changes in the hydrological regimen in watersheds, (ARABI et al., 2006; VANZELA; HERNANDEZ; FRANCO, 2010; BLAINSKI et al., 2011). Andréassian (2004) indicates that the increase of the forested area causes a decrease of the maximum peak flow, and an increase in the base flow discharge values. These changes can be attributed mainly to changes in evapotranspiration, roughness, and water infiltration rate in the soil.

In other similar studies, Bracmort et al. (2006) and Blainski et al. (2014) do not identify significant effects on the water regimen in the studied basins associated with modifications to land use/land cover.

This result suggests that the intrinsic diversity of the watershed characteristics could define the degree of dependence between these two variables.

The results presented in this study make it possible to identify how changes in land use/land cover affect the hydrological regime of the CRB with more intensity at the extremes of the exceedance probability graph (Figure 5). For the scenarios of 2012 and 1978, an increase in the maximum peak flows of about 28.0% and 11.1%, respectively, were identified. These changes are probably associated with the increase of irrigated rice fields, deforestation, and urban uses in these years. In addition, the emergence of early stages of forest plantation areas may have contributed to these results in the 2012 scenario. For the dry season, when compared to the 1957 scenario, the simulated flow suffers a reduction of 11.1% and 33.3% corresponding to the same scenarios. In the intermediate stages, the difference between scenarios was not significant; the results fall within the range of uncertainty of the model, calculated at 0.56 m^3 s^{-1} for this range.

The hydrographs (Figure 6) for the water intake point (Figure 2) were generated in two years with different pluviometry volumes: 2006 – 1,409 mm year^{-1} (the lowest volume of annual rainfall recorded) and 2008 – 2,474 mm year^{-1} (highest annual accumulated rainfall). The results show that there was a change in the hydrological pattern caused by the change in land use/land cover, independent of the annual volume of precipitation.

In the 1957 scenario, the lowest flow amplitudes were estimated. This means that in the dry period, the highest base flows were recorded and in the wet period, the lowest peak flow
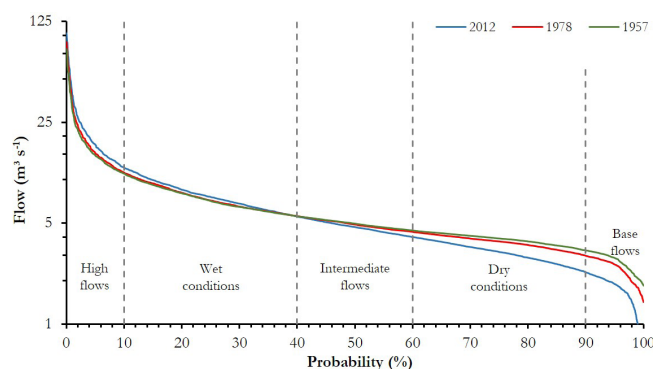
Table 3. Land use/land cover areas (ha) of the CRB by scenarios for 2012, 1978, and 1957.

LU/LC (ha)	Year		
	2012	1978	1957
Water	98.7	38.4	37.7
Urban	1,571.3	649.4	22.0
Annual crops	69.6	131.7	415.8
Forest	12,095.6	11,627.2	12,479.8
Pasture	3,280.4	5,374.9	5,625.9
Bare soil	235.6	50.9	26.1
Rural roads	322.1	316.4	302.6
Irrigated rice fields	1,103.8	1,066.1	343.9
Forest plantation	477.9	0	0

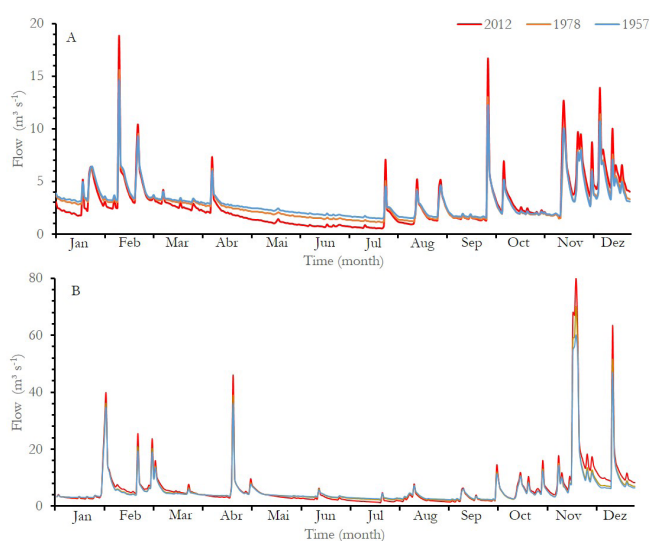**Figure 5.** Exceedance probability graph for daily flow for a period of 10 years in the land use scenarios.

Figure 6. Simulated hydrographs in the three scenarios (m³ s⁻¹) for the water intake watershed, in two years with distinct pluviometry characteristics; A-2006 (low rainfall year) and B-2008 (high rainfall year).

was recorded. This behavior suggests a tendency to smooth the fluctuations of the hydrograph curve.

In the 2012 scenario, for the two cases (Figures 6A and 6B), the lowest base flow rates were recorded in dry conditions and the highest peak flows in wet conditions, thus corroborating the results obtained in other studies that associate the increase of high flows to the replacement of natural landscapes by agricultural or urban uses (ANDRÉASSIAN, 2004; ARABI, et al., 2006; VANZELA; HERNANDEZ; FRANCO, 2010; BLAINSKI et al., 2011).

Soil erosion simulation

Estimation of erosion rates and identification of areas with the highest occurrence are important components of river basin management. Figure 7 shows the mean distribution of simulated erosion in the land use/land cover scenarios for the specified sub-basins.

In the 1957 scenario, the lowest rates of soil loss were identified. The scenario has a low amount of urban area and the smallest area of irrigated rice fields among the three simulated
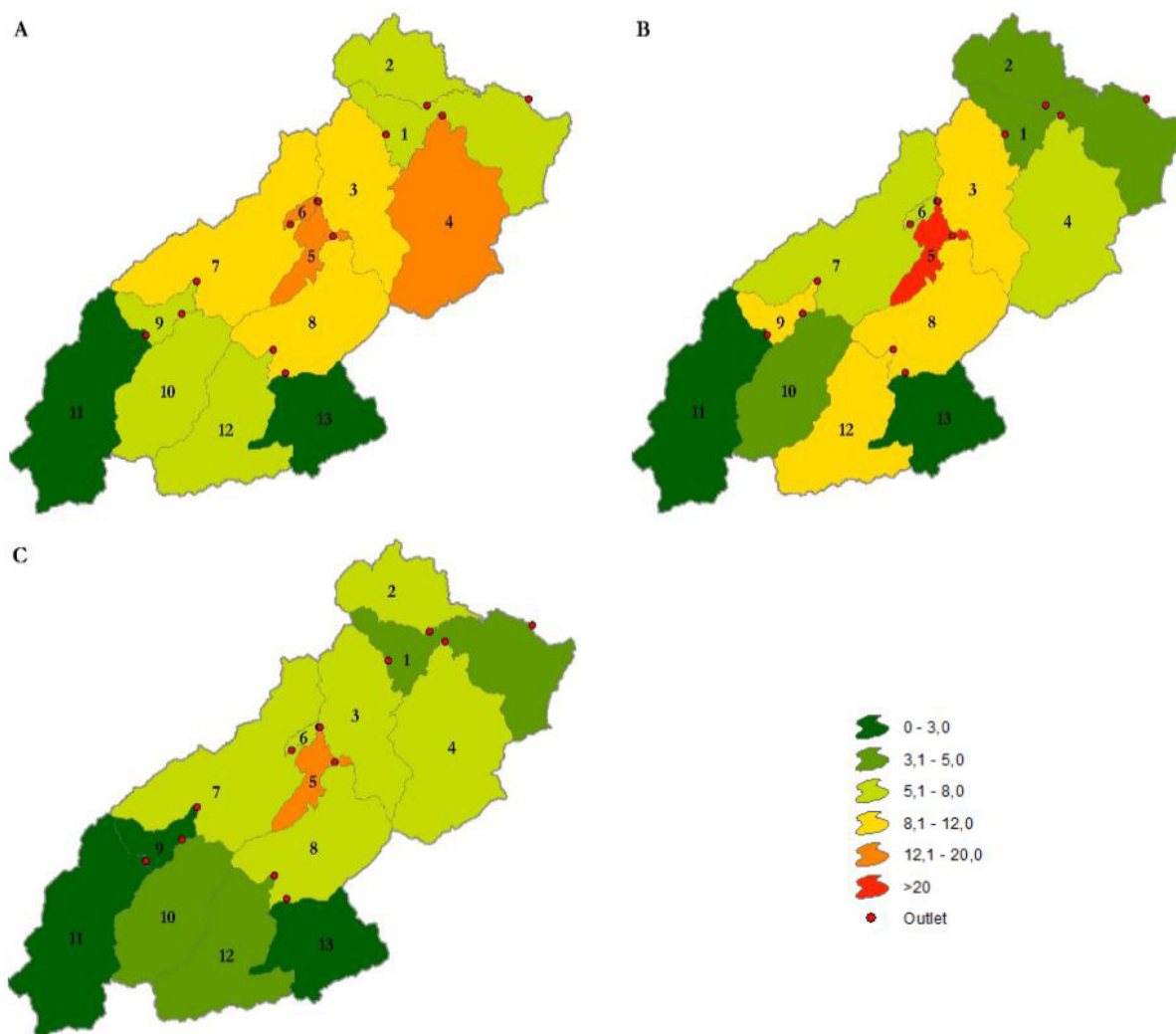

Figure 7. Spatial distribution of simulated soil erosion by sub-watershed, in (A) 2012; (B) 1978; and (C) 1957 scenarios. The numbers in the maps are the delimited sub-watersheds.

scenarios (Table 3). The maximum soil loss was 14.6 t ha⁻¹ year⁻¹. Excluding the sub-watershed 5, soil loss was lower than 8.0 t ha⁻¹ year⁻¹ (Figure 7); in about 48% of the river basin area, the erosion rate was below 5.0 t ha⁻¹ year⁻¹.

In sub-watershed 5, about 36% of the area is occupied by pasture and 8.2% by irrigated rice fields. According Brooks et al. (1991), pastures associated with steep terrain and/or erosion-susceptible soils may have a high rate of soil loss, which probably explains the data recorded in this area. The authors also explain that sediment production increases when the riparian zone is also used for pasture, increasing erosion of the river bank and the eventual deposition of sediments in the river bed.

Another important factor related to soil loss and forest land cover, according to Wischmeier and Smith (1978), is the natural erosion control produced by the forest cover; they found that the interception and vegetal cover protect the soil surface from the direct impact of raindrops. Furthermore, forest cover promotes improvement in soil structure and infiltration rates, and an increase in water retention capacity; in addition, the soil roughness characteristics increase surface friction, which generates a decrease in surface runoff velocity (BERTONI; LOMBARDI NETO, 2010).

In the 1978 scenario, soil loss was numerically higher than in the 1957 scenario (Figure 7), mainly in sub-basins in which the change in soil use was more intense.

In sub-watershed 5, soil erosion was estimated to be 41.0 t ha⁻¹ year⁻¹. The high rate can be attributed to land use alterations and their implications for related processes, such as water infiltration capacity, runoff, conservation practices, and crop management.

For the same area, in 1957, the irrigated rice fields occupied about 8.2% of the total area, while forested areas extended to 52.0% of the total sub-basin. In the 1978 scenario, the rice crops increased against a decrease of the forested areas, causing the percentages to change to 36.5% and 29.4%, for rice and forests respectively. Similar behavior was observed in sub-basins 9, 8, and 3 (Figure 2).

In the 2012 scenario, soil loss was higher than in other scenarios (Figure 7). Thus, as previously reported, the substitution of forested areas for agricultural uses was the main factor associated with an increase of soil loss. In this particular scenario, the irrigated rice fields increased for the middle river basin, the site with the highest rates of soil loss (Figure 7). Compared to the 1978 scenario, in sub-watershed 5 and 12, the reduction of soil loss is mainly due to the increase of forested areas and the decrease of pasture areas. In addition, in sub-watersheds 1, 2, and 4, the increased rate of erosion was mainly due to the reduction of forested areas and the increase of irrigated rice fields.

Figure 8 shows the average soil erosion in the river basin estimated from each simulated scenario, from 2006 to 2015. The results compare variations in soil erosion for the proposed scenarios and the temporal variations in the simulated years.

As previously reported, variations in land use/land cover that were identified among the studied scenarios could be the main causes of the variations in soil erosion rates in the CRB.

The temporal variations observed in the erosion estimates can be attributed to strong variations in the recorded volume of precipitation. This parameter is directly correlated to the surface

runoff rate and contributes to the increase of the flow water and the related volume of transported solids.

The variations in precipitation recorded between 2006 and 2008 reflect a significant change in the erosion rate, independent of the simulated scenarios. For the 1957 scenario, characterized by the lower influence of human activity, average soil erosion was 1.40 t ha⁻¹ year⁻¹ and annual precipitation was 1,409 mm. In the same scenario in 2008, annual rainfall reached 2,474 mm and soil loss was about 14.8 t ha⁻¹ year⁻¹.

The results in Figure 8 demonstrate the strong influence of rainfall on the soil erosion process, perhaps influenced by the increase in runoff rate in years characterized by high rainfall rates (Figure 9).

Throughout the studied period, the highest surface runoff rate was found in the 2012 scenario, followed by the 1978 and 1957 scenarios, respectively. Changes in vegetal cover (Table 1) resulted in changes in the roughness coefficient and the water infiltration rate; consequently, scenarios with the highest surface runoff rates are those having a higher number of areas with exposed soil, irrigated rice fields, and urban areas.

A considerable portion of the CRB lies within the accepted limits for estimated erosion rates (BLAINSKI et al., 2011), considering the type of soils and the topography factors in the study region. According to the authors, in the Ribeirão Gustavo (SC) river basin, with soil and climatic characteristics similar to the study area, the average tolerance to soil erosion was estimated at 7.83 t ha year⁻¹. Therefore, for the 1957 and 1978 scenarios, and
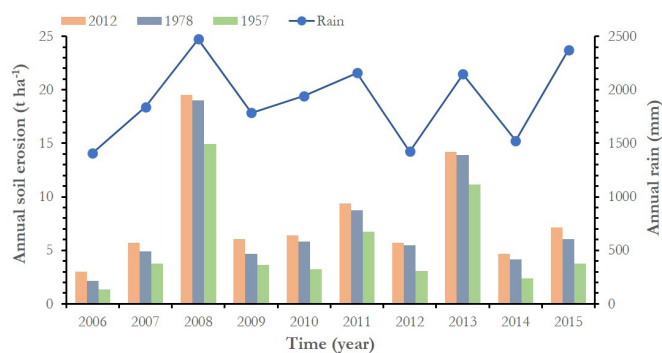

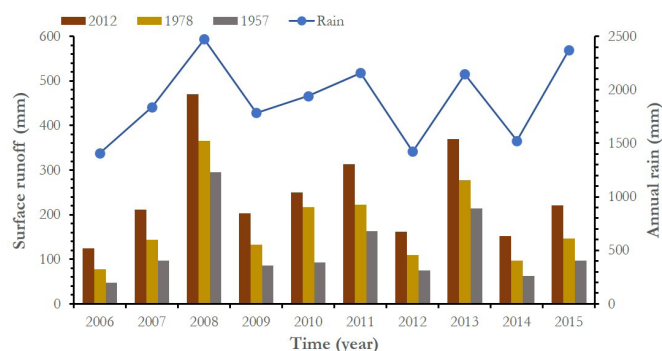**Figure 8.** Soil erosion simulations for 2012, 1978, and 1957 for the CRB.

Figure 9. Surface runoff simulations for 2012, 1978, and 1957, for the CRB.

in the sub-watershed with the largest forested area, soil loss falls within naturally tolerable values.

However, the results indicate that the soil and climatic characteristics could increase soil degradation, especially in years with high volumes of rainfall. In addition, Figure 7 shows the impact of replacing natural landscapes with agricultural activities, in this case rice crops and pasture land. The higher rate of soil loss is linked to watersheds where land use classes related to human activity were predominant, or in sub-watersheds where soil loss was notoriously greater than in the areas occupied by forests.

The principal factor related to the increased rate of soil loss in the crop-related land use classes is excessive tilling methods, which can cause soil compaction, loss of infiltration capacity, and high susceptibility of these soils to erosion. In pasture areas, this increase in erosion may be associated with the reduction of the natural vegetation cover, soil compaction by animal trampling, and lack of conservation practices. This combination of factors, in association with areas of high slope, significantly increases the velocity of surface runoff, and consequently, soil loss.

Finally, the change in land use and occupation results in a significant change in the hydric and sediment regimen of the CRB. In the literature, numerous papers describe the role of vegetal cover in controlling soil loss and increasing water availability (PANACHUKI et al., 2011; CARDOSO et al., 2012; DIAS, 2012; GALHARTE et al., 2014; PEREIRA et al., 2014). In this work, however, through hydrological modeling, it was possible simulate the landscape changes recorded over 55 years of occupation and their impacts on the hydrosedimentological dynamic, generating strategic information for the management of the hydrographic basin and for the prioritization of interventions seeking environmental preservation and the sustainability of agricultural activities.

CONCLUSION

In this study, adjustments to the SWAT calibration parameters provided satisfactory configuration for modeling the discharge and sediment regimen of the CRB. Thus, it was possible to quantify the changes in the variables of flow for three land use/land cover scenarios, TSS, and soil loss in this river basin.

The main simulated flow changes in the scenarios for 1957, 1978, and 2012 occurred at the extremes of the probability of exceedance. In the intermediate range, the differences remained close to the model's uncertainty range.

For soil loss, sub-basins with predominantly agricultural uses showed the highest values. However, in the period studied, the CRB did not report severe problems of soil loss. The results also indicate that soil and climatic characteristics may favor soil degradation, especially in years with a high volume of precipitation.

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Luis Hamilton Pospissil Garbossa: Responsible for multiparameter probe implantation, writing and revision.

Adilson Pinheiro: Contribution in papper conception, analysis and completion of the results, review and compliance the journal guidelines.