CIÊNCIAᵉNATURA

Efeitos de mudança de uso do solo na vazão do rio Paraíba do Sul

Effects of land use change on discharge of the Paraíba do Sul river

Caluan Rodrigues Capozzoli [I]; Andrea de Oliveira Cardoso [II]

Resumo

A bacia do rio Paraíba do Sul está localizada na região sudeste do Brasil e compreende parte dos estados de São Paulo, Rio de Janeiro e Minas Gerais. Além da população urbana e rural da bacia, o rio Paraíba do Sul abastece cerca de doze milhões de pessoas na Região Metropolitana do Rio de Janeiro, a terceira maior região metropolitana da América do Sul. O uso da terra na bacia é predominantemente para pecuária leiteira, onde o manejo inadequado do solo tem influenciado a qualidade e a quantidade de água na bacia. Neste trabalho, um modelo hidrológico distribuído foi utilizado para avaliar diferentes cenários de cobertura superficial, considerando incrementos da cobertura florestal ao longo dos cursos de água da bacia. Os cenários foram comparados com a condição atual da bacia em termos de vazão média anual, vazão máxima diária anual e frequência de ocorrência de extremos de vazão muito alta e muito baixa. Os resultados apontam para redução da vazão média anual com o aumento da cobertura florestal e redução dos valores de vazão máxima diária anual. A análise de frequência de extremos indica que o aumento da cobertura florestal promove diminuição dos eventos de vazão muito alta e aumento dos eventos de vazão muito baixa durante os meses chuvosos da bacia (outubro a março), no entanto, nos meses secos (especialmente em agosto) a ocorrência de eventos de vazão muito alta aumenta enquanto os eventos de vazão muito baixa diminuem. estes resultados indicam que, embora em termos médios e durante o período chuvoso a cobertura florestal afete negativamente a disponibilidade hídrica superficial, nos meses mais secos, quando o recurso hídrico é mais escasso, o aumento de cobertura florestal é benéfico para disponibilidade hídrica da bacia.

Palavras-chave: Mudança de uso do solo, modelagem hidrológica, vegetação ripária.

Abstract

The Paraíba do Sul river basin is located in the southeast region of Brazil and across São Paulo, Rio de Janeiro and Minas Gerais states. In addition to the urban and rural population in the basin, Paraíba do Sul River supplies about twelve million people in the Metropolitan Region of Rio de Janeiro, the third-largest metropolitan region in South America. Land-use in the basin is predominantly dairy farming, where inadequate soil management has affected the quality and quantity of water in the basin. In this work, a distributed hydrological model was performed to assess different surface coverage scenarios considering increments of forest cover along to the basin watercourses. The scenarios were compared with the current condition of the basin in terms of annual mean streamflow, annual maximum daily streamflow, and frequency of occurrence of very high and very low flow extremes. The simulations indicate a reduction in the annual mean streamflow rate due to the increase of the cover forest; reduction of annual maximum daily streamflow due to the increase in forest cover. Extreme frequency analysis indicates that increasing forest cover promotes a decrease in very high flow events and an increase in very low flow events during the rainy months of the basin (October to March), however, in the dry months (especially in August) the occurrence of very high flow events increases while very low flow events decrease. These results indicate that although on average and during the rainy season forest cover negatively affects surface water availability in the driest months, when water resources are scarcer, increased forest cover is beneficial for water availability in the basin.

Keywords: Land-use changes, hydrological modeling, riparian vegetation.

[I] Geological Survey of Brazil - https://orcid.org/0000-0002-8846-9393 caluan.capozzoli@cprm.gov.br
[II] Federal University of ABC - https://orcid.org/0000-0001-9914-7501- andrea.cardoso@ufabc.edu.br

1   Introduction

The Paraíba do Sul River Basin (PSRB) covers three large states in the southeastern region of Brazil (São Paulo, Rio de Janeiro, and Minas Gerais). The PSRB drainage area (around 55.000 km^2) live more than 5 million people, it covers several hydropower plants and a very important industrial and population centers of Brazil.

Among the conflicts that occur due to the use of water in the basin, we highlight the diversion of water from PSRB for the generation of energy and the supply of approximately 20 million people in the Metropolitan Region of Rio de Janeiro (MRRJ). The MRRJ is the second-largest metropolitan region of Brazil and the third largest of South America.

Land use in the Paraíba do Sul River basin over the 18th century was predominantly focused on coffee cultivation. However, inadequate soil management and deforestation of native vegetation decreased the productive capacity for agriculture and gradually the land use in the basin has turned to the still predominant dairy farming. Recently the urban growth of the basin has been stimulated and currently, 87% of the population lives in urban areas of the basin.

Intensive practices, using slash-and-burns methods without concern for the conservation of soil, water resources and biological diversity, result in low productivity and represent an enormous waste of natural resources, especially the water of the basin, which is affected in quantity and quality by inadequate soil management.

The Brazilian National Water Resources Policy highlights in its objectives the rational and integrated use of water resources and the need to guarantee water availability for the present and future. In the context of water resource management, hydrological modeling can be an important tool for understanding the impacts of land use and land cover changes (LULC) on hydrological behavior.

Several studies have been carried out to evaluate the impact of LULC on the hydrological response. Viola et al. (2014) evaluated LULC scenarios using the Lavras Simulation of Hydrology (LASH) model (Mello et al., 2008), identifying reductions (increase) in annual mean streamflow when pasture cover (eucalyptus forest) is replaced by eucalyptus (pasture) forests. Using Soil & Water Assessment Tool (SWAT) Li et al. (2016) distinguished rainfall reduction impacts and LULC impacts in streamflow for different sub-basins of the same river basin in China.

In work carried out in the Pomba river basin (a PSRB sub-basin), Pereira et al. (2016) compared different LULC scenarios considering an increase of the pasture area or an increase of the preserved area and in all cases a reduction tendency in the average annual flow was observed about the current condition of the basin.

Simulations impacts of forest removal in a basin with high rates of deforestation in the Amazon show results consistent with observational studies conducted in the same area (Rodriguez e Tomasella, 2016).

A major review of the results of both observational studies and using hydrological modeling is presented by Zhang et al. (2017) and highlights the sensitivity of large basins to land use and land cover change which is more pronounced in basins where precipitation is limiting (this is the case in PSRB). In many studies of this nature, the evaluation of the impacts of land use and land cover change is limited to the annual mean flows.

Most literature analyzes the LULC impacts in terms of annual averages and the results are reasonably well established. However, the interannual and monthly scale is little explored. The objective of this research was to assess the impacts of different land cover change scenarios in the PSRB on an annual and monthly scale.

2   Materials and methods

In this study, the MGB-IPH model (Acronym in Portuguese to Large Basin Model - Institute of Hydraulic Researches) version 2015 was used for hydrological simulation in PSRB on a daily scale. The MGB-IPH model is a distributed hydrological model developed in Brazil (Collischonn et al., 2007). It consists of the following modules: soil water balance; evapotranspiration; surface, sub-surface and underground flow in the cell; drainage network.

The simulations are performed in two steps: In the first, preprocessing module, soil type and land use information are synthesized in the form of Hydrological Response Units (HRU) and associated with topographic information. After that, the input variables (streamflow, rainfall, and other atmospheric variables) and parameterizations of the model are read and the simulation is performed.

The MGB has ten calibration parameters: soil water storage capacity, form of the relation between storage and saturation, underground drainage, subsurface drainage, soil porosity index, capillarity, residual storage, parameters related to delay of the simple linear surface, subsurface and groundwater reservoir model and four fixed parameters: albedo (α), leaf area index (LAI), tree height (H) and surface resistance (Rs). Each HRU of the basin will be associated with different values of calibration and fixed parameters. More detailed information about the concepts and formulation of the model can be found in Collischonn et al. (2007).

2.1   Description of Paraíba do Sul River Basin

The drainage area of PSRB is around 55,000 square kilometers and covers São Paulo (24% area), Minas Gerais (35% area) e Rio de Janeiro (41% area) states. It is located between approximate latitudes 20º and 23º South and longitudes 41º and 46º West. The

PSRB is situated in a rugged relief region with a more extensive area of the plain near the river mouth. The basin is bounded by two large mountain ranges: Mantiqueira to the northwest and Serra do Mar to the southeast and both play an important role in increasing precipitation in mountainous regions (Figure 1). According to the detailed Köppen classification for Brazil (Alvares et al., 2013), the climate basin is considered humid subtropical with dry winter and hot or temperate summer (Cwa or Cwb) in most of the basin, except the northwest region which is classified as tropical with dry winter (Aw).
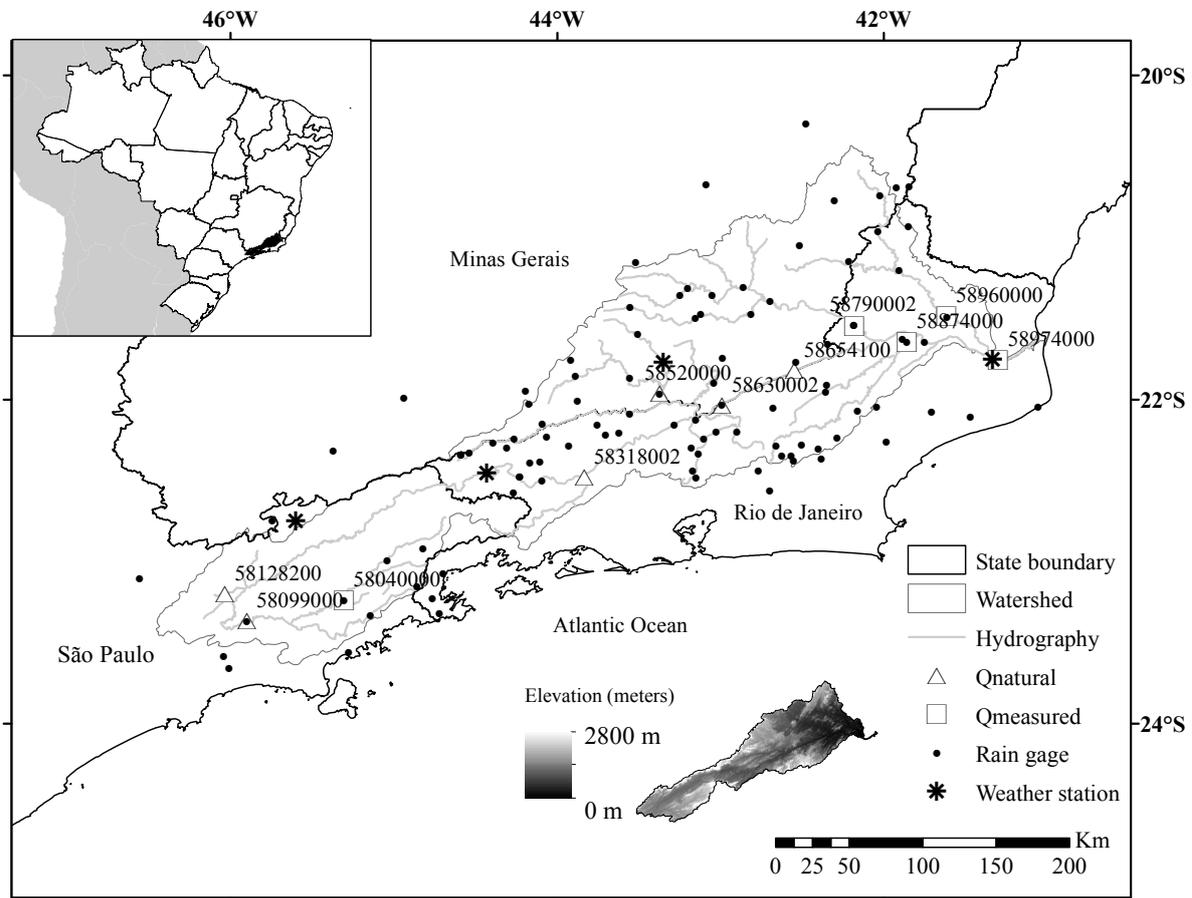

Figure 1: Geographic location of Paraíba do Sul River Basin, pluviometric, fluviometric and climatological stations used. Qnatural refers to the locations where natural streamflow are reconstruct considering dam operation and water use and Qobs are streamflow calculated at conventional fluviometric monitoring using level gages and rating curve

2.2 Data base

This work used daily rainfall and daily measured streamflow available in the National Water Agency (ANA - acronym in Portuguese) database and daily natural streamflow available by the National Operator of the Electrical System (ONS - acronym in Portuguese).

It is relevant to distinguish daily measured and natural streamflow once this should be considered in the interpretation of this work. The daily measured streamflow is generated from level observation and streamflow rating curves in stage gages.

Natural streamflows are a daily streamflow series that represent a close natural behavior of the river if human action were minimized. It is obtained considering observation at streamflow gauges upstream and downstream of reservoir operations and then effects from dam operation, pumping, transpositions between river and canals, bypasses and evapotranspiration are removed from the original series. More details can be found in ONS. National Operator of the Electrical System (2007).

The daily rainfall refers to accumulated precipitation in 24 hours collected daily at 7 am. Once it is important to have a good spatial and temporal representation of rainfall variability in the basin, 106 rain gauges distributed over basin were used to rainfall interpolation. For streamflow were used data from 5 stream gages points of daily measured streamflow and 5 points where daily natural streamflow is calculated. The daily data of air temperature, relative air humidity, wind speed, atmospheric pressure were obtained in the database from the National Institute of Meteorology.

Table 1: Information of fluviometric station used for study development

Code	Name	Drainage Area (Km^2)	Natural or Measured streamflow?	Reference to calibration
58040000	São Luís do Paraitinga	1,950	Measured	No
58099000	Santa Branca	4,940	Natural	Yes
58128200	Jaguari	1,300	Natural	No
58318002	Santa Cecília Jusante	16,700	Natural	Yes
58520000	Sobraji	3,640	Natural	Yes
58630002	Anta	32,700	Natural	Yes
58654100	Porto Velho do Cunha	34,400	Natural	Yes
58790002	Santo Antônio de Pádua II	8,210	Measured	No
58874000	Dois Rios	3,120	Measured	No
58960000	Cardoso Moreira	7,210	Measured	No
58974000	Campos - Ponte Municipal	55,700	Measured	No

To determine the HRU it is necessary to cross the information of soil type and land use. The soil and land cover information was obtained from maps produced by the Paraíba do Sul River Basin Management Committee.

The digital elevation model (DEM) was generated from the Shuttle Radar Topography Mission (SRTM) (http://srtm.csi.cgiar.org/) with a resolution of approximately 30 meters, and the correction of possible existing depressions was done using the Modify Heuristic Search algorithm of the MGB (Siqueira et al., 2016).

2.3   Calibration and validation

To simulate the hydrological impacts resulting from the LULC scenarios designed for the region, the model was calibrated and validated by continuous simulation of the daily flow. The calibration period is from 01/01/2005 to 12/31/2009 and the verification period from 01/01/2010 to 12/31/2015. The period used for calibration and validation is longer than 5 years and covers medium, wet and dry years. In this way, the interval used is sufficient to ensure that all the constituent processes of the model are requested during the calibration and validation (Gan et al., 1997).

Considering also that the data used to calibrate model simulations have a direct effect on the validation and evaluation results (Moriasi et al., 2007), the simulation period was delimited so that the percentage of failures in annual daily rainfall is less than 10% in any year of simulation. The calibration and validation assessment was performed by Nash-Sutcliffe (NS), its logarithmic version (Nlog) (Nash e Sutcliffe, 1970); and percentual bias (PBIAS) (Gupta et al., 1999). The reference values for each coefficient followed those suggested by Moriasi et al. (2007) (table 2).

Table 2: Reference values to performing classification of Nash (NS), Log Nash (NLog) e PBIAS

Performance classification	NS and NLog	PBIAS
Very good	NS >0.75	|PBIAS|<10%
Good	0.65<NS≤0.75	10%≤|PBIAS|< 15%
Satisfactory	0.50<NS≤0.65	15%≤|PBIAS|< 25%
Unsatisfactory	NS0.50	|PBIAS|≤25%

To ensure that values of calibration parameters are representative of natural condition flow in the basin, the calibration adjust (that is the fit of simulated with observed hydrogram) was performed only naturalized flow data. However, Nash, LogNash, and PBIAS coeficients were calculated for all streamflow point in both periods (calibration and simulation).

An accuracy test was performed using a contingency table as described by Wilks (2006) to evaluate the model's ability to represent extremes. The thresholds of very low flow and very high flow were determined by percentiles 15% and 85%, respectively, for each month of simulation. More details about threshold criteria can be obtained in Pinkayan (1966)

2.4   Scenarios of land-use changes

The maintenance of riparian vegetation along watercourses is provided in Brazilian Federal Law 12.651 / 2012. According to this law, the strip of riparian vegetation (PRV) that must be maintained depends on the width of the watercourse. For watercourses up to 10m wide, the PRV is 30 m for each side of the watercourse, counted from the regular bed. The PRV increases to 50 m, 100m, 200m and 500m to watercourses with a width of 10m to 50m, 50m to 200m, 200m to 600m and more than 600m, respectively.

Water balance assessments in the forest and/or cultivated areas indicate that vegetation in the flood plain may influence a hydrological response (Tabacchi et al., 2000). In this work, 12 land-use scenarios were generated with progressive increases of PRV along watercourses in PSRB. These projections were made using forest cover dampers with 30 m, 50 m and from 100 m to 1000 m with a 100 m increment between the scenarios. The daily streamflow was simulated for each scenario and the impacts were evaluated comparing the scenario that represents actual land cover (control scenario) with the land-use change projections.

3   Results and discussion

In the calibration period, the NS and PBIAS values were unsatisfactory at two points in the upper part of the basin. The explanation for the poor performance at these points is associated with the small drainage area of these sub-basins and the coarse spatial distribution of rain gauges. For the other points, the performance was satisfactory to very good (Figure 2). The performance classification shown in figure 2 was made according to table 2.

In general, the results obtained for the verification period are consistent with the calibration period. The same points in the upper part of the basin presented unsatisfactory performance. The Nash coefficient result shows slightly better performance for the verification period, NLog performance was lower, and PBIAS was similar to the performance of the calibration period.

The NLog coefficient is heavily influenced by modeling performance during recession periods. In the verification period, there was a severe drought in the basin and the river flow was the lowest recorded in historical series. Given that observed streamflow is calculated using a level/discharge measurement rating curve. This rating curve may be poor for very low flow conditions because there are few (or none) discharge measurements in low levels, in this case, a rating curve established at a level where discharge measurement is taken is extrapolated to generate flows. This procedure can generate uncertainties in the observed streamflow.
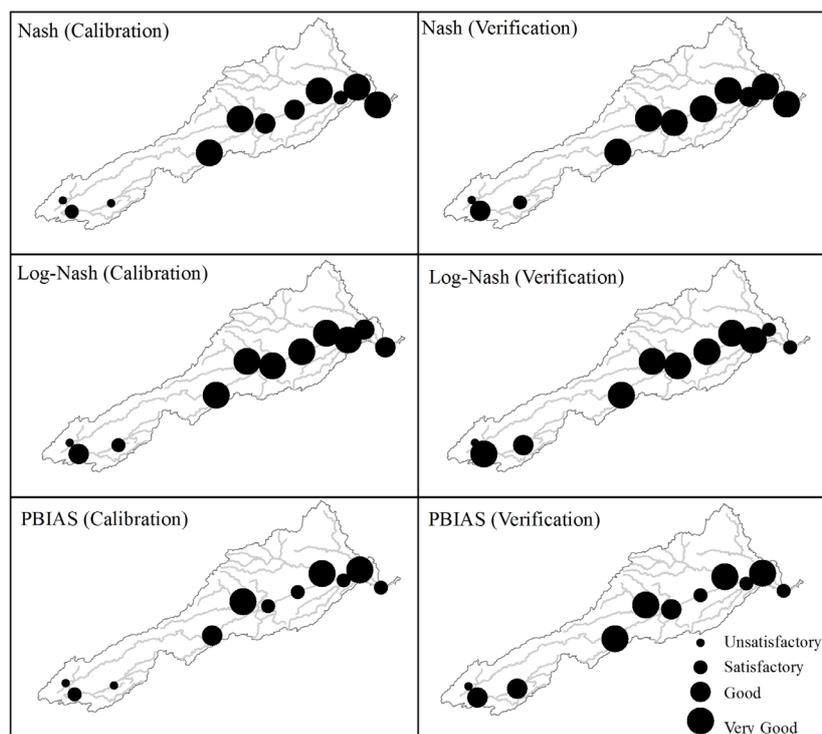

Figure 2: Classification of the Nash, Log-Nash and PBIAS coefficients for the calibration (left) and verification (right) periods. Calibration period is from 01/01/2005 to 12/31/2009 and verification period is from 01/01/2010 until 12/31/2015

To evaluate the capacity of the model in the representation of flow extremes considering the seasonal variation, the monthly accuracy for the entire period was verified as described in methodology (figure 3). The result of the accuracy test shows that the model can represent well the extremes (very low and very high flow) at the same points where other coefficients indicated good calibration, the exceptions occur in stations 58960000 and 58974000, in this points very high flow in dry months is poor.

The current land cover condition of the basin is 48.2% agricultural and 44.1% forest. In the condition of maximum PRV (1000 m), agricultural cover reduces 9.5% and forest cover increases 10.8%.

The evaluation of the results is presented comparing actual conditions with hypothetical scenarios of PRV. The annual average flow (AAF), annual maximum daily flow (ADF) and the frequency of very low and very high flow in each scenario are compared with current condition land cover. The analysis was performed in all fluviometric monitoring stations shown in figure 1. Due to
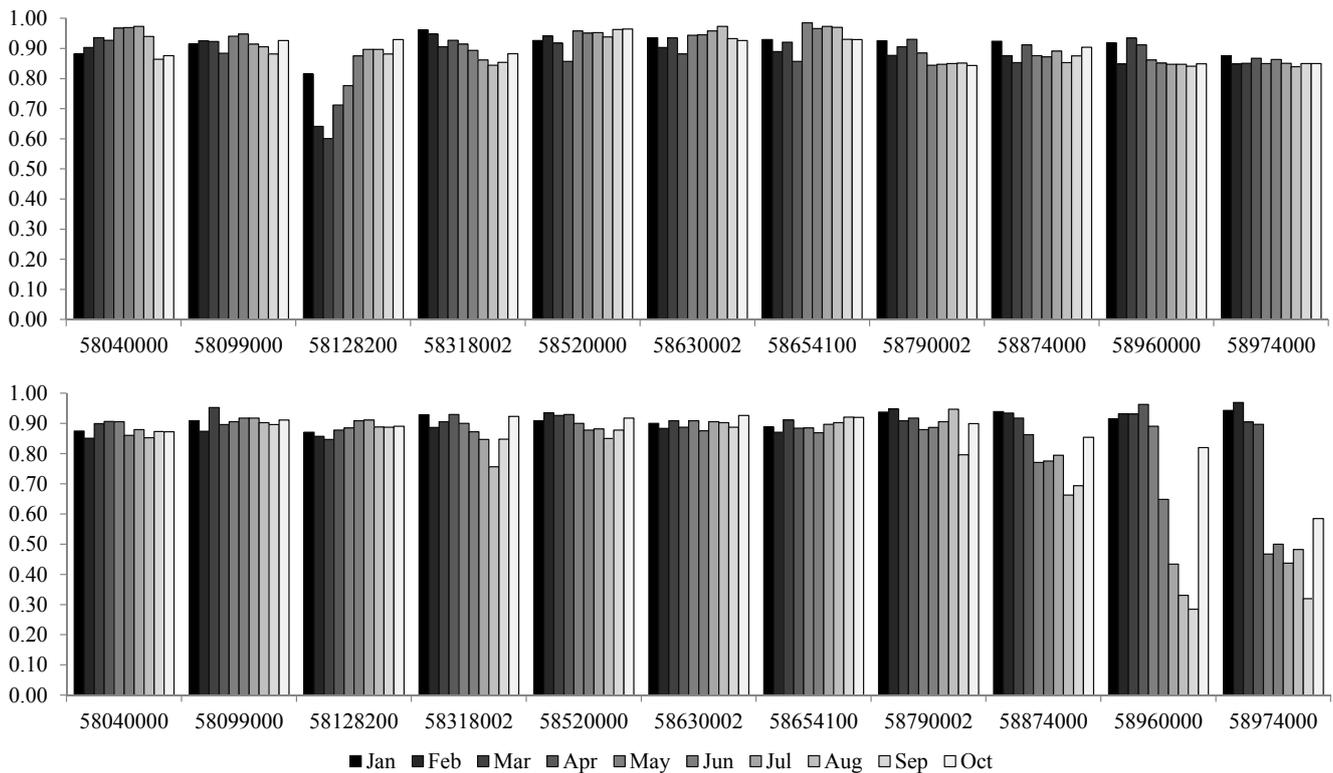
Figure 3: Accuracy for occurrence of very high (above) and very low (below) flow events for each month of the year for total simulation period

similarities, the results will be presented for the point 58318002 – Santa Cecília Jusante where the river water is transposed to supply MRRJ (figure 1).

The results of the scenarios indicate a reduction in the average annual flow due to the increase of PRV along the watercourses and in all the analyzed points, the magnitude of the reduction is not constant throughout the simulation years of the scenarios.

Comparing the magnitude of the average flow reduction in 2014 with the magnitude of the average flow reduction in the year 2010, it is possible to note that the reductions in the years with the highest AAF (which were rainier in the basin) more than in the years with the lowest AAF. The year 2014 is recognized as one of the most severe droughts recorded in the entire southeastern region of Brazil, where the Paraíba do Sul river basin (Coelho et al., 2016).

This result indicates that the hydrological response to the type of cover in the margin, in terms of AAF, is also dependent on the total precipitation in the basin. The theoretical explanation for this is that the vegetation increases infiltration and storage capacity by interception and then a larger portion of the precipitation is infiltrated and evaporated reducing runoff. In years where rainfall is exceptionally low, like in the years 2014 and 2015, the increased storage capacity promoted by vegetation has little influence on the streamflow behavior.

For each year of simulation, the ADF was determined both for the control and for each PRV scenario. The ADF decreases with forest cover increases (Figure 5) and the magnitude of the reduction is variable annually. In years where the magnitude of the ADF is higher, the percentage of reduction in the scenarios is lower, Whereas when the ADF is lower, the reduction is percentage higher. This result is consistent since basin drainage conditions are predominant in peak attenuation in smaller flood events, while in larger floods the peak attenuation effect is lower (Niehoff et al., 2002).

The results of the comparison between the frequency of very high and very low flow events are presented, considering that very high flow events correspond to daily flows with values higher than the 85% percentile and very low flow events, daily flows lower than the 15% percentile. It should be noted that the percentile thresholds were determined separately for each month of the year using the daily flows of the control simulation. The frequency of monthly occurrence in each of the scenarios was compared to the frequency of occurrence in the control, based on the whole period (2005 to 2015). The result of the frequency analysis of monthly flow extremes is quite diverse for each of the analyzed stations. However, some general results can be summarized. To simplify the presentation and discussion, the results were separated according to the rainy and dry period of the basin.

The figure 6(a) shows the frequency of extremes (very high and very low) for the rainy season. Between October and March, the very high flow rate decreases due to the increase in the forest cover. This behavior may be associated with an increase in the
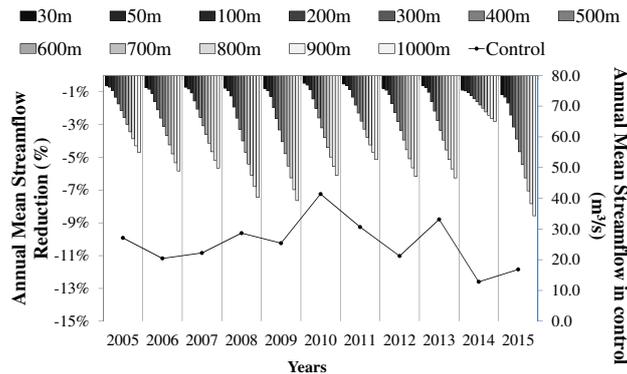
Figure 4: Reduction in the average annual flow (AAF) depending on the width of the preservation riparian vegetation (bars) and AAF in control scenario (line)
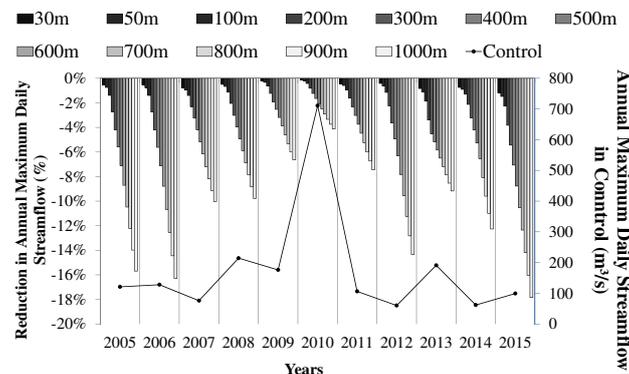

Figure 5: Reduction in annual maximum daily streamflow (ADF) depending on the width of the preservation riparian vegetation (bars) and ADF in control scenario (line)

storage capacity of the surface reservoir of the model through interception. The LAI of forest area is higher than other URH types. The larger volume intercepted favors evaporation and decreases the precipitated volume which is converted into a flow. The forest cover also has a higher water storage capacity in the soil, which can contribute to reducing runoff. Additionally, the flow rates of the transition months, although larger than the dry season, are still most common for the annual basin regime, with vegetation peaking attenuation being predominant for events with shorter return period (Tucci e Clarke, 1997).

Another common result for all the analyzed stations is the increase in the frequency of very high flows due to the increase of the PRV range in August. This result may be associated with higher storage capacity promoted by forest cover, thus ensuring higher flows during the dry period. To analyze the frequency of very low flow rates, it is possible to highlight that the analyzed stations indicated an increase in the frequency of very low flows due to the increase of the PRV range for the months of the rainy period of the basin.

The results of reducing the frequency of very low flows and enhancing the frequency of very high flows during the drought months indicate that the maintenance of forest cover can reduce the impact of droughts in water availability, despite reducing the flows in terms of annual averages

4   Summary and Conclusions

The MGB model was calibrated and verified for the Paraíba do Sul river basin. The results indicate that the model can adequately represent the rainfall-runoff process into the basin. Scenarios considering forest cover increment in PRV were evaluated in terms

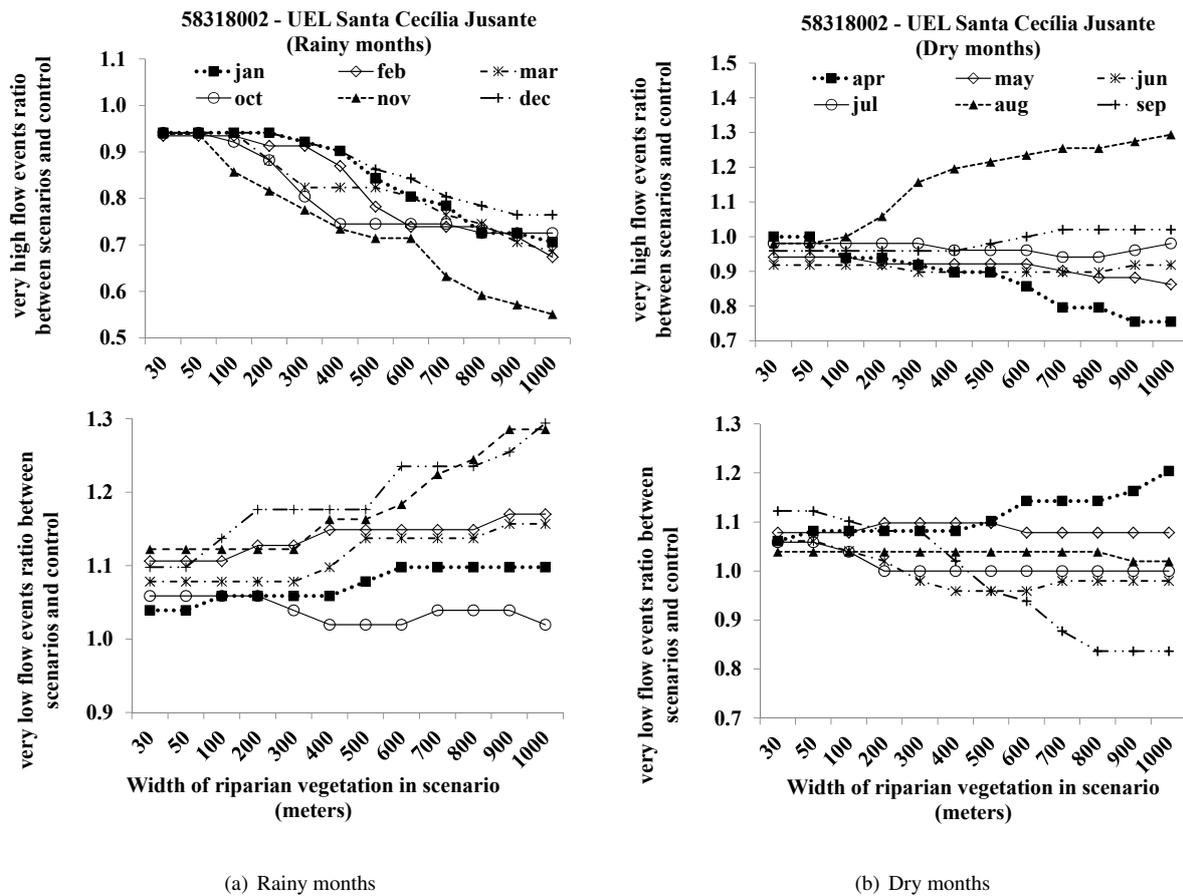(a) Rainy months   (b) Dry months

Figure 6: Rate Frequency of very high (above) and very low (below) flow in rainy (a) and dry (b) season for each scenario of riparian vegetation increase (x axis)

of AAF, ADF, and frequency of very high and very low flow events. The results indicate a reduction in the annual mean streamflow due to forest cover increase. This reduction is more pronounced in the years that annual mean streamflow is higher. In the year of severe drought (2014) this reduction was very small than years with ordinary annual rainfall amounts. The ADF decreases according to increment in forest cover and the reduction magnitude is variable annually. In years where the magnitude of the ADF is higher, the percentage of reduction in the scenarios is lower, whereas when the ADF is lower, the reduction percentage is higher.

In the rainy months, very high flow frequency reduce and very low flow increase in both cases the variation is more pronounced in the transition months. During the dry months, the variations due to the increase of PRV are less pronounced, highlighting the behavior in August when very high flow frequency is positively sensitive to the increase in PRV.

The results of this work suggest that, from the hydrological point of view, forest cover is an important mechanism of maintenance and / or improvement the environmental services, contributing to the reduction of flood peaks and maintenance of base flow (fundamental to guarantee water availability during the driest periods of the basin).

For future work, it is suggested the application of methodologies to increase the reliability of the parameterization performed, since the correct parameterization of the model is a fundamental step in the results of the scenarios. For example, comparing the parameterization with the results of other hydrological models not only focused on the rainfall process but also with specialized vertical flow models like a SiB2 (Sellers et al., 1996).

Acknowledgements

References

Alvares, C. A. S., Stape, J. L., Sentelhas, P. C., Moraes, J., G.and Leonardo, Sparovek, G. (2013). Köppen's climate classification map for brazil. *Meteorologische Zeitschrift*, 22(6), 711–728.

Coelho, C. A. S., Cardoso, D. H. F., Firpo, M. A. S. (2016). Precipitation diagnostics of an exceptionally dry event in são paulo. *Theoretical and Applied Climatology*, *125*, 769–784.

Collischonn, W., Allasia, D., Da Silva, B. C., Tucci, C. E. (2007). The mgb-iph model for large-scale rainfall—runoff modelling. *Hydrological Sciences Journal*, *52*, 878–895.

Gan, T. Y., Dlamini, E. M., Biftu, G. F. (1997). Effects of model complexity and structure, data quality, and objective functions on hydrologic modeling. *Journal of Hydrology*, *192*, 81–103.

Gupta, H. V., Sorooshian, S., Yapo, P. O. (1999). Status of automatic calibration for hydrologic models: Comparison with multilevel expert calibration. *Journal of Hydrologic Engineering*, *4*, 135–143.

Li, J., Li, G., Zhou, S., Chen, F. (2016). Quantifying the effects of land surface change on annual runoff considering precipitation variability by swat. *Water resources management*, *30*, 1071–1084.

Mello, C. D., Viola, M. R., Norton, L. D., Silva, A. M., Weimar, F. A. (2008). Development and application of a simple hydrologic model simulation for a brazilian headwater basin. *Catena*, *75*, 235–247.

Moriasi, D. N., Arnold, J. G., Van Liew, M. W., Bingner, R. L., Harmel, R. D., Veith, L. D. (2007). Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. *Transactions of the ASABE*, *50*, 885–900.

Nash, J. E., Sutcliffe, J. V. (1970). River flow forecasting through conceptual models part i—a discussion of principles. *Journal of hydrology*, *10*, 282–290.

National Operator of the Electrical System (2007). Streamflow series update – 1931–2006 period (in portuguese). Technical report, National Operator of the Electrical System, http://ons.org.br.

Niehoff, D., Fritsch, U., Bronstert, A. (2002). Land-use impacts on storm-runoff generation: scenarios of land-use change and simulation of hydrological response in a meso-scale catchment in sw-germany. *Journal of Hydrology*, *267*, 80–93.

Pereira, D. D. R., Martinez, M. A., Da Silva, D. D., Pruski, F. F. (2016). 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. *Journal of Hydrology: Regional Studies*, *5*, 149–163.

Pinkayan, S. (1966). Conditional probabilities of occurrence of wet and dry years over a large continental area. *Hydrology papers*, (12), 149–163.

Rodriguez, D. A., Tomasella, J. (2016). On the ability of large-scale hydrological models to simulate land use and land cover change impacts in amazonian basins. *Hydrological Sciences Journal*, *61*, 1831–1846.

Sellers, P. J., Randall, D. A., Collatz, G. J., Berry, J. A., Field, C., Dazlich, D. A., ..., Bounoua, L. (1996). A revised land surface parameterization (sib2) for atmospheric gcms. part i: Model formulation. *Journal of climate*, *09*(4), 676–705.

Siqueira, V. A., Fleischmann, A. S., Jardim, P. F., Fan, F. M., Collischonn, W. (2016). Iph-hydro tools: a gis coupled tool for watershed topology acquisition in an open-source environment. *Brazilian Journal of Water Resources*, *21*, 274–287.

Tabacchi, E., Lambs, L., Guilloy, H., Planty-Tabacchi, A. M., Muller, E., Decamps, H. (2000). Impacts of riparian vegetation on hydrological processes. *Hydrological Processes*, *14*, 2959–2976.

Tucci, C. E. M., Clarke, R. T. (1997). Impacto das mudanças da cobertura vegetal no escoamento: revisão. *Revista Brasileira de Recursos Hídricos*, *02*(1), 135–152.

Viola, M. R., Mello, C. R., Beskow, S., Norton, L. D. (2014). Impacts of land-use changes on the hydrology of the grande river basin headwaters, southeastern brazil. *Water Resources Management*, *28*, 4537–4550.

Wilks, D. S. (2006). *Statistical Methods in the Atmospheric Sciences*, 2º edn. Academic Press.

Zhang, M., Liu, N., Harper, R., Li, Q., Liu, K., Wei, X., et al (2017). A global review on hydrological responses to forest change across multiple spatial scales: Importance of scale, climate, forest type and hydrological regime. *Journal of Hydrology*, *546*, 44–59.