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Impacts of Deforestation on Climate and Water Resources in Western Amazon

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1. Introduction

The Amazon importance in several areas of research demonstrates how the region affects the balance of South America and, depending on the scale used, on the planet. The biodiversity, mineral wealth, water resources wealth, carbon sequestration, transport of energy in the atmosphere are examples of important aspects of the region. Another important phenomenon that occurs in the Amazon are the energy flows between soil-vegetation-atmosphere dynamics that affect the climate, water resources and the advection of moisture to the surrounding parts.

Deforestation is the major environmental problem in the Amazon River basin nowadays, and its impacts affect both the local and global scale. In fact, this region is responsible for approximately 13% of all global runoff into the oceans (Foley et al., 2002) and its abundant vegetation releases large amounts of water vapor through evapotranspiration leading to a recycling in precipitation of about 25-35% (Brubaker et al, 1993; Eltahir and Bras, 1994; Trenberth, 1999).

Rondonia State, located in Western Amazon, already has a large area of vegetation changed by deforestation. Historically, there were tax incentives and government so that there was an expansion of development. Today the concern with changes in environmental balance of the Amazon basin, Rondônia, is justified by the increasing pressure on various forms of exploitation of the region, for example, timber extraction and agricultural expansion, the construction of hydropower, exploitation of biological and mineral riches.

Krusche et al. (2005) suggest the following reasons for this progress: between 1970 and 1990 there was a surge in state occupancy with settlers coming from other regions, extensive cattle ranching became the main economic activity and the state ground most is old and weathered, with the exception of some basins, promoting agriculture in an appropriate area. According to the authors, the pattern of occupancy was observed of the "fishbone" associated with the opening of roads.

The highway BR-364construction, responsible for turning the region with the rest of the country, was one of the factors that triggered large projects of colonization / occupation. Earlier this deforestation process was seen as boon, as a prerequisite for applying for tenure and subsequent legalization of land (Santos, 2001). Fearnside (2007) assert that the main aspect of change in land use / land cover in region is deforestation, and that it has grown over the years.

Deforestation rates of the State during the period 1988 to 2007 followed, in general, the same degradation that deforestation in the Amazon, since it has to be estimated. The most relevant peaks occurred in 1994 and 2004, showing a slight decrease for the years 2005 to 2007, however, leaving the state responsible for a higher percentage than the last 10 years earlier, reflecting a greater intensity on change in coverage plant that closed in the rest of the Amazon.

Year	Deforestation (km2)		%
	Rondönia	Amazon	
1988	2340	21050	11.10
1989	1430	17770	8.00
1990	1670	13730	12.20
1991	1110	11030	10.10
1992	2265	13786	16.40
1993	2595	14896	17.40
1994	2595	14896	17.40
1995	4730	29059	16.30
1996	2432	18161	13.40
1997	1986	13227	15.00
1998	2041	17383	11.70
1999	2358	17259	13.70
2000	2465	18226	13.50
2001	2673	18165	14.70
2002	3067	21651	14.50
2003	3620	25396	14.40
2004	3834	27772	14.00
2005	3233	19014	17.00
2006	2062	14286	14.70
2007	1611	11651	13.82
2008	1136	12911	10.00
2009	482	7464	6.45%
2010	427	6451	6.6%

Table 1. Annual deforestation rates - Amazon and Rondônia (Source data: Prodes, Inpe)

Public policies has been working to combat deforestation across the Amazon, we can observe the decrease in the rate since 2007, however, has been observed that in conservation areas this rate is increasing.

The proposal chapter is investigating the impacts that deforestation and climate change can lead on hydrological cycle in the region, as well as the feedback system of climate and hydrological cycle.

2. Metodology

The study is centered in Rondônia state, whose area of about 234.000 km2. The state's network runoff is represented by Madeira river (an important tributary of the Amazonian river basin) and its streams that form eight important sub river basins, among them, it is the Jamari sub river basin (Fig. 1). About 28% of the Rondônia state have already been deforested, because of this, is used as the test catchment study.

The Jamari river basin has suffered a substantial deforestation due to the advance of the agricultural frontier in the Rondônia state. The basin is crossed by two important rivers namely Jamari and Candeias. Jamari river has its nascent in the southwest part of "Serra do Pacaás Novos", in Rondônia, and streams northward flowing into the right bank of Madeira river, whose river basin is defined by the geographical coordinates 08º 28'S to 11º 07'S of latitude and 62º 36'W to 64º 20'W of longitude with about 29.066.68 km² of area.

The semi-distributed hydrological model SLURP with more detailed input parametric information will be used in this research in order to investigate the impacts caused by deforestation as well as climate changes on hydrological processes in Jamari River basin. Realistic and extremes scenarios of deforestation will be analyzed, and also scenarios of temperature rise and precipitation increase/decrease.

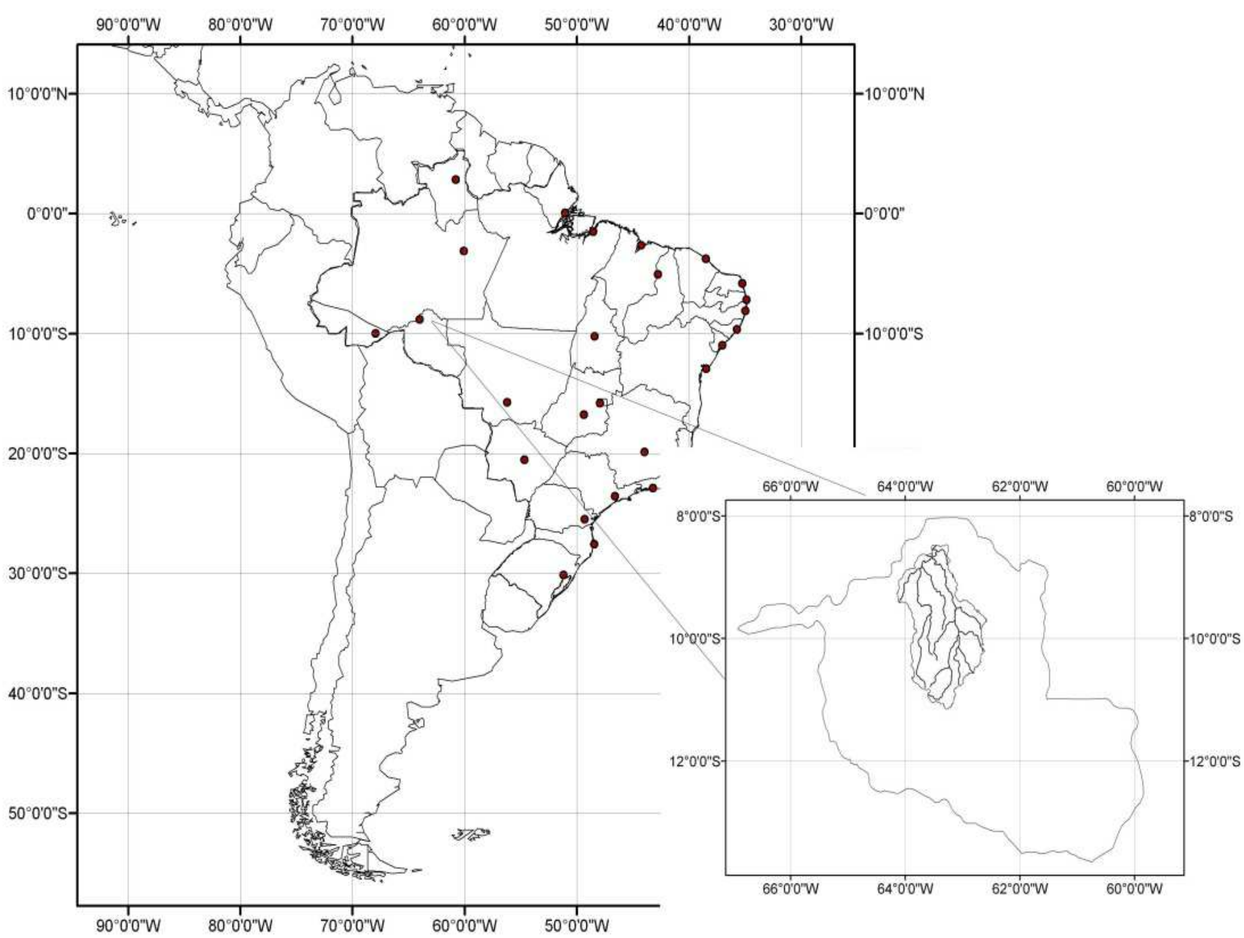


Fig. 1. Localization and drainage network Jamari sub river basin.

2.1 Hydrological model

Semi-distributed Land Use-based Runoff Processes - SLURP is a basin model that simulates the hydrological cycle from precipitation to runoff including the effects of reservoirs, regulators and water extractions (Kite, 2005). First divides a basin into sub-basins using topography from a digital elevation map. These sub-basins are further divided into areas of different land covers using data from a digital land cover classification. Each land cover class has a distinct set of parameters for the model.

This model uses basically three types of data: i) digital elevation data (DEM); ii) land cover data; and iii) climatic data. The matrix data of both DEM and land cover data must have the same dimension. Climatic data should contain: precipitation, air temperature, dew-point temperature (or relative humidity), solar radiation and wind intensity. Firstly, it divides a hydrological basin into sub-river basins and then divides each sub-river basin into land cover components using the public-domain topographic analysis software TOPAZ (and Martz and Garbreht, 1999). These homogeneous areas are based on the hydrological response unit (HRU) concept described by Kite (2005). SLURP defines these areas as Aggregated Simulation Areas (ASA).

The model has been applied in many countries for small hectares basins (Su et al., 2000) to large basins such as Mackenzie (Kite et al., 1994) and it was developed to make maximum use of remote sensing data. Applications of the model includes studies of climate change (Kite, 1993), hydropower (Kite et al., 1998), water productivity (Kite, 2005), irrigation (Kite and Droogers, 1999) and wildlife refuges (de Voogt et al., 1999), contribution of snowmelt to runoff (Laurente and Valeo, 2003; Thorne and Woo, 2006), and large mountainous catchment (Thorne and Woo, 2006). However, the SLURP model was not used in the Amazon, and its conceptual approach allows its use in regions with little data, as well as the possibility and direct use of remote sensing data which allows to retrieve physical parameters with good accuracy, even in basins with small slopes, as found in some sub-basins in the Amazon River.

2.2 Data

Digital Elevation Model - DEM from the Shuttle Radar Topography Mission (SRTM) with 90-m resolution horizontal was used to obtain topography. In order to correct failures, it was used the technique of space filtering, interactive filling.

For actual land cover data it was used seven images of Landsat 7 scenes 2007 over the Jamari sub-river basin, resolution of 30m, provided by Amazonian Protection System (SIPAM). Firstly, the scenes were georeferenced and then a mosaic was composed. Secondly, NDVI performed a supervised classification to obtain the land-cover image. Then, the data was sampled again to 90m resolution, since the SLURP requires that the matrix of land cover has the same size of DEM. Finally, the data was classified into four classes: water, forest, non-forest and man-modified (urbanized). The non-forest class includes agricultural areas and the savannah.

2.3 Climatic, rainfall and runoff data

Climatic, rainfall and runoff data are some of the main difficulties in hydrometeorological modeling in the Amazon. The time series available is short and has many flaws. Was used data set from four stations with information about precipitation, air temperature and dew point of the Agency for Environmental Development in Rondônia (SEDAM). We also use data from five rainfall gauge of the National Water Agency (ANA). The data sets are from the period between 1 January 1999 and December 31, 2007.

2.4 Model performance evaluation criteria

Model performance was evaluated by using four different error measures: Nash and Sutcliffe (NS), Percent BIAS (PBIAS), Daily Root Mean Square (DRMS) error criteria (Zhi et al., 2009; Moriasi et al., 2007), and Deviation Volume (D%) (Kite, 2005). The equations were given as showed below:

$$NS = 1 - \frac{\sum_{i=1}^{n} (Q_{obs} - Q_{mod})^2}{\sum_{i=1}^{n} (Q_{obs} - \overline{Q_{obsd}})^2} \quad (1)$$

where Qobs and Qmod are the measured and modeled data, respectively; . $\overline{Q_{obsd}}$. is average modeled data; and n is the total number of data records. The coefficient can range from -∞ to 1 and represents the amount of data oscillation that is explained by the model. The model is considered optimal if NS = 1, appropriate and good if NS > 0.75, acceptable if 0.36 <NS <0.75, and unacceptable if NS <0.35. If NS < 0, the predictor is worse than the average (Nóbrega, 2008).

$$PBIAS = \frac{\sum_{i=1}^{n} (Q_{obs} - Q_{mod})}{\sum_{i=1}^{n} Q_{obs}} \quad (2)$$

where Qobs and Qmod are the measured and modeled data, respectively. The optimal value of PBIAS is 0. Low magnitude values indicate accurate model simulation; PBIAS > 0 indicate model underestimation bias; and PBIAS < 0 indicate model overestimation bias (Zhi, 2009).

$$PBIAS = \frac{\sum_{i=1}^{n} (Q_{obs} - Q_{mod})}{\sum_{i=1}^{n} Q_{obs}} \quad (3)$$

RSR varies from optimal value of 0, which indicates zero RSME or residual variability and therefore perfect model simulation, to large positive values; the smaller RSR the better the model simulation performs (Zhi, 2009; Kannan et al., 2007).

$$D_V(\%) = 100.\frac{Q_{obs} - Q_{mod}}{Q_{obs}} \quad (4)$$

This criterion is simply a change in the pattern of calculated and observed average in the simulated period, which is a statistical test comparing the simulated discharge volumes to measures during the event, generating information about performance of the water balance total modeled. A value of zero indicates optimal modeling, or no difference between the volumes measured and simulated. A positive value indicates underestimation of the simulated volumes (losses in origin). A negative value indicates that the calculated average flow is high (losses in sinks) (Kite, 2005).

3. Simulations

Based on the percentage of deforestation in the basin obtained from the PRODES data (Table 2) it was defined two trends scenarios: i) DEFOR+20, 20% more deforestation area, and ii) DEFOR+30, 30% deforestation area. It was defined three extreme scenarios of land cover for investigating the relationship between soil-cover change and runoff within SLURP model. The experiments are: i) 100%FOR, one hundred per cent with forest and water; ii) 100%NOFOR, one hundred per cent with savannah plus pasture and water; and iii) 100%MANMODIF, one hundred per cent man-modified area and water. For climatic impacts analysis has been used two scenarios. The scenarios were based in climate futures projections up to 2050 A2 HadCM3 model, discussed in Marengo (2006b). In both scenarios is assumed that the temperature rise 2^{o}C, and rainfall varies 20%, decreasing and increasing. The climate scenarios are: i) P+20, meaning 20% increase in rainfall, with an increase in temperature of 2 degrees, and ii) P-20, meaning 20% reduction in rainfall, with an increase in temperature of 2 degrees.

SCENARIO	DESCRIPTION
DEFOR+20	20% more deforestation area
DEFOR+30	30% more deforestation area
100%FOR	100% forest area
100%NOFOR	100% savannah plus pasture
100%MANMODIF	100% man-modified area
P+20	20% increase in rainfall, and 2oC temperature increase
P-20	20% decrease in rainfall, and 2oC temperature increase

Table 2. Simulations scenarios

3.1 Problems identified – implementation of necessary remedial measures

SLURP model needs data from weather stations which contains precipitation, temperature, humidity and wind. The average is calculated using the Thiessen polygons method for each ASA. If there is no such data, the model does not perform the simulation (for example, when there is rainfall data, but there is not temperature).

In some countries, such as Brazil, it is common to have only rainfall station, instead of weather station, making the network rainfall much denser than the weather. But the compilation of the model does not allow the use of this data. Aiming to overcome this limitation, we tried to develop a methodology that would use the climatic stations without changing the source code of the model. Adopted method is based on the concept that the spatial variability of precipitation is less than the other data, such as temperature. Then, without the model, it was calculated the mean rainfall for each ASA also using the Thiessen method, but including the data from rainfall stations. After that, the files of average precipitation for each ASA were replaced.

4. Results and discussion

Jamari sub-river basin was automatically divided by SLURP into five aggregate similar areas (ASAs) according to the DEM and land cover data (Fig. 2). For each ASA it was obtained the percentile area of land cover occupied for each of the four classes: i) water; ii) forest; iii) non-forest; and iv) man-modified (Table 3). The total basin area obtained by the model is 28.847 km² (~99% of the total area, according to Government State official data).
The model was calibrated and checked by the two different types of data: i) weather stations data (OBS1); and ii) weather station data added rainfall gauge station (OBS2). Obviously it is expected that the use of a denser network of precipitation within a basin simulation results in improvements, since the data quality is consistent, but it was not clear if the model would accept the manual modification.

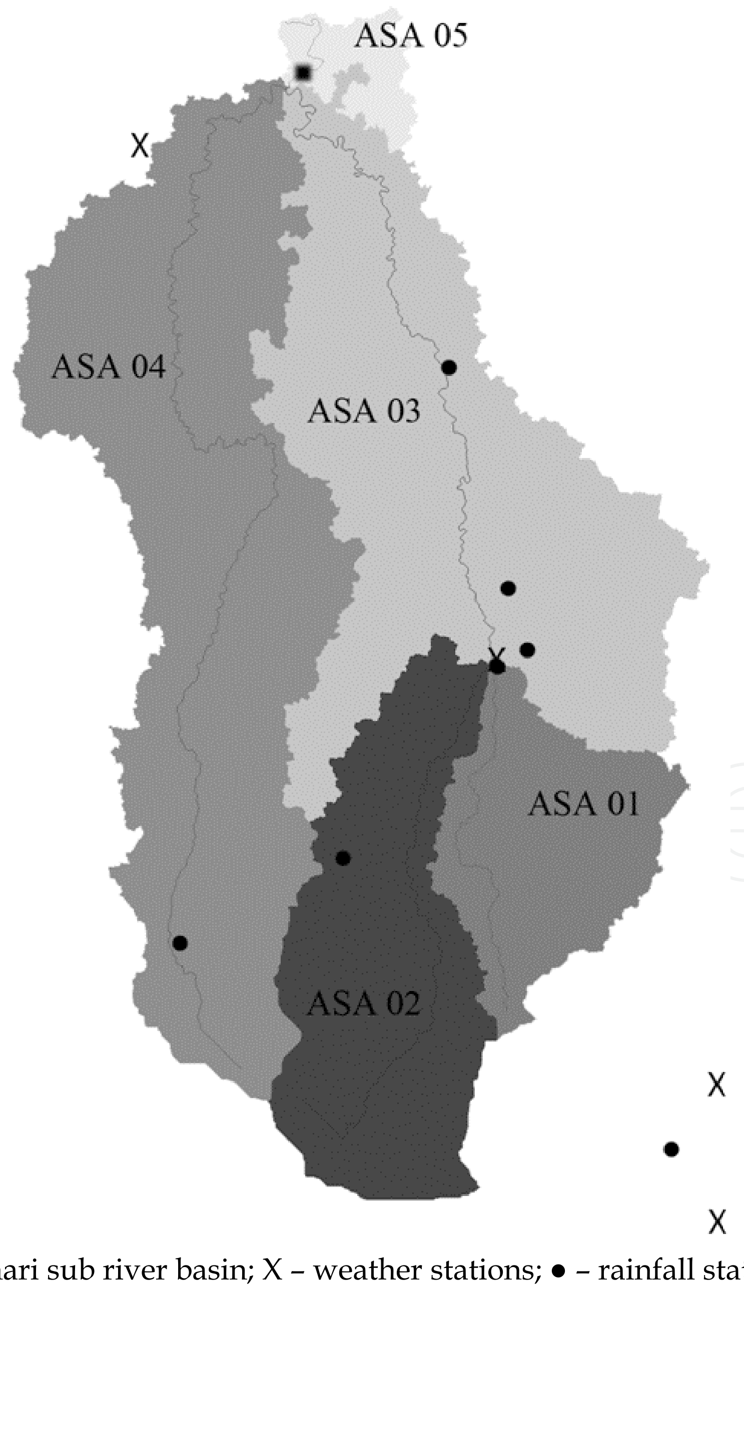


Fig. 2. ASAs for Jamari sub river basin; X – weather stations; ● – rainfall station

ASA Name	Water	Forest	Non forest	Man modified	Total (km^2)
ASA 01	9.0	63.0	7.8	20.2	3025.81
ASA 02	3.6	67.3	11.7	17.4	5007.65
ASA 03	9.3	61.3	7.0	22.4	9239.68
ASA 04	3.9	62.2	11.4	22.5	10999.55
ASA 05	4.1	93.8	2.0	0.1	573.94

Table 3. Land coverage and total area for each ASA (%)

The NS, RSR, PBIAS and D(%) for OBS2(OBS1) calibration period was 0.88(0.74), 0.31(0.45), -7%(-12%) and -0.94%(-10.1%), respectively. The NS, RSR, PBIAS and D(%) for OBS2(OBS1) validation period was 0.84(0.71), 0.34(0.48), -8%(-15%) and -13.4(-10.3). The verification of the model efficiency criteria indicates that the values are acceptable during both the calibration and validation period. (Table 3), but it is clear that the model did better with the inclusion of climatic stations. From this point, we used OBS2 data with SLURP climate input.

4.1 Calibration and verification

Model was calibrated and verified by the two different types of data: i) weather stations data (OBS1); and ii) weather station data added rainfall gauge station (OBS2). Obviously it is expected that the use of a denser network of precipitation within a basin simulation results in improvements, since the data quality is consistent, but it was not clear if the model would accept the manual modification.

The NS, RSR, PBIAS and D(%) for OBS2(OBS1) calibration period was 0.88(0.74), 0.31(0.45), -7%(-12%) and -0.94%(-10.1%), respectively. The NS, RSR, PBIAS and D(%) for OBS2(OBS1) validation period was 0.84(0.71), 0.34(0.48), -8%(-15%) and -13.4(-10.3). Model efficiency criteria verification indicates that the values are acceptable during both the calibration and validation period (Table 4), but it is clear that the model did better with the inclusion of climatic stations, therefore, used OBS2 data with climate input.

OBS2 (OBS1)	NS	RSR	PBIAS	D(%)
Calibration	0.88 (0.74)	0.31(0.45)	-7%(-12%)	-0.94 (-10.1)
Verification	0.84 (0.71)	0.34(0.48)	-8% (-15%)	-13.4 (-10.3)

Table 4. Model performance

4.2 Deforestation impacts

Taking into account the current deforestation rate in the area which is being studied, the trend scenarios can be designed by 2013 and 2016, respectively. The results for DEFOR+20% and DEFOR+30% indicated increased runoff compared to the average from 1999-2007, 825.3 $m^3.s^{-1}$, to 1048.1 $m^3.s^{-1}$ and 1163.7 $m^3.s^{-1}$, resulting in an increase of 27% and 41%, respectively. During the dry season (characterized by a weak runoff), the flow trends to increase remarkably, what can be a concern for local population who use these rivers for human supply, navigation (in some places, the only kind of transportation), and also for power generation. If these scenarios become real, the rivers of the basin will be subjected to a different runoff pattern that might cause some socioeconomic impact. Although the extreme scenarios are not realistic, the results are instructive because they clarify the non-linear response of the hydrological cycle to the progressive changes in land cover.

When modifying the land cover to 100%FOR, the annual calculated runoff average decreased from 825.3$m^3.s^{-1}$ to 329.1 $m^3.s^{-1}$, i.e., a decrease of about 60%. On the other hand, for the scenarios with 100%NOFOR and 100%MANMODIF, runoff increased to 2313.1$m^3.s^{-1}$, and 1729.4$m^3.s^{-1}$, an increase of 181%, and 109% of the observed annual runoff average, respectively.

The parameters that most influenced the results in these scenarios were related to the amount of available soil water for evapotranspiration and canopy interception, which were modified according to the soil cover. The high interception in scenario 100%FOR leads to a reduction of precipitation that reaches the soil and thus reduces runoff. It also reduces the amount of water available for evaporation. Furthermore, the increase of flowing in scenarios 100%NOFOREST and 100%MANMODIF is due to the substantial decrease in evapotranspiration and rainfall interception by the canopy. It is worth mentioning that this study used the same series of precipitation for all scenarios, but the precipitation in the region is a variable that has its intensity, largely influenced by local evaporation. Hence, decrease in evapotranspiration tends to reduce rainfall. The use of SLURP coupled to an atmospheric model can reveal more about this feedback mechanism in further studies.

The elements of water balance are shown in Fig. 3. It may be noticed that evapotranspiration varies slightly between the scenarios, except the 100%NOFOR, where evapotranspiration is approximately 90% the value of the other scenarios. However, when the exchange of water between the surface and the atmosphere is divided into evaporation and transpiration, the peculiarities of each scenario are quite evident. In 100%FOREST, transpiration contributed to the increase of evapotranspiration. This is quite obvious, since in this scenario, the interaction between the surface and free atmosphere is dominated by the exchange of processes in the vegetation canopy. In 100% NOFOREST, the land cover formed by the typical savanna and pasture vegetation makes the transpiration to be twice as much as evaporation. In 100% MANMODIF, the deforested soil with urban characteristic implies a greater contribution in evaporation than in transpiration.

It can be observed that the evapotranspiration and groundwater reduces slightly with the decrease of forest areas when we compare with the trend scenarios. In terms of numbers the evapotranspiration decreased from 20% to 30%, respectively; groundwater flow decreased 20% and 8%, respectively. As long as deforestation leads to less water interception by vegetation, the contribution of evaporation increases with the expansion of the deforested area.

Several studies suggest the local contribution of evapotranspiration as responsible for about 50% of the precipitation that occurs in western Amazonia (Nóbrega, 2005; Marengo, 2006a; Nóbrega, 2008). Therefore, a decrease in vegetation cover over a region can alter the precipitation regime is this region (and neighborhood), decreasing the amount of water vapor originated there, because the evapotranspiration decreased in these simulated scenarios, and this trend, combined with the increase in flowing during dry periods, may worsen social and environmental problems during more critical periods.

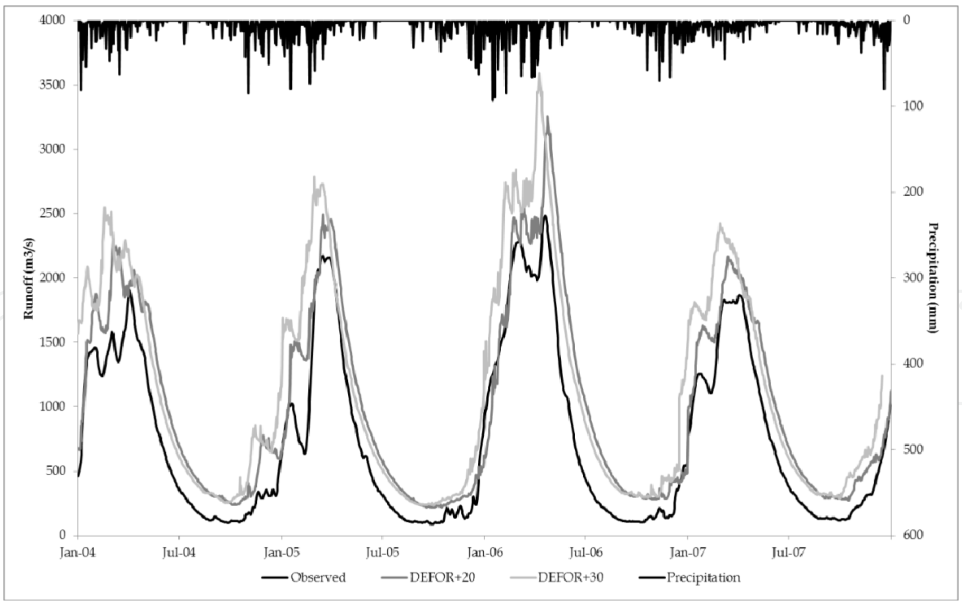


Fig. 3. Observed and Simulated water balance components for scenarios DEFOR+20% and DEFOR+30

4.3 Climate change impacts

Daily changes in runoff due to temperature and precipitation variations are shown in Fig. 4. The effect when the rainfall increases or decreases in 20% was as expected. An increase in rainfalls tends to increase runoffs, and a decrease in rainfalls tends to decrease runoffs, which is more noticeable during the rainy season, when rains are more significant. For the scenario P +20, the runoff increased 31%, and setting P-20 decreased 13%, indicating that a increase rainfall will respond more significantly than the decrease in this specific region.
These results allow an analysis that a decrease in rainfall may have a critical effect especially during the rainy season, affecting navigation, agricultural production, human consumption and power generation. Fig. 5 shows the seasonal average flow for the investigation period, confirming that the impacts are more significant during the rainy season.

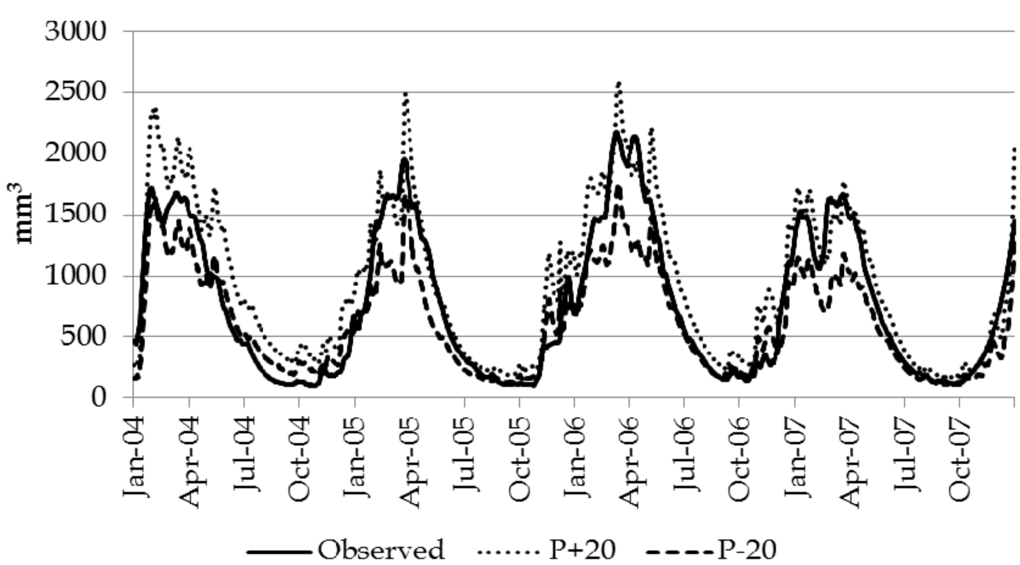


Fig. 4. Observed and Simulated runoff for scenarios P+20 and P-20

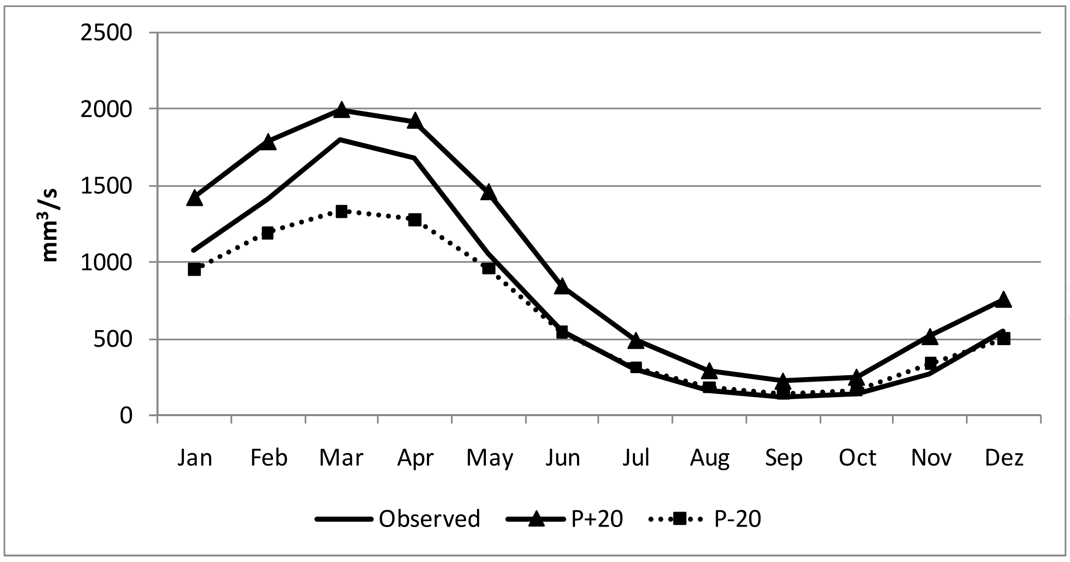


Fig. 5. Superficial runoff monthly average Observed and simulated for scenarios P+20 and P-20

Water balance changes due to changes in temperature and precipitation, it was observed that an increase in temperature tends to increase transpiration in both scenarios, and a decrease in rainfall tends to reduce evaporation (Fig. 6). The evapotranspiration increases 30% and 54%, evaporation decreases 21% and increases 3%, transpiration increases 37% and 41%, and groundwater decreases 35% and 33% for the sets of P-20 and P +20 respectively.

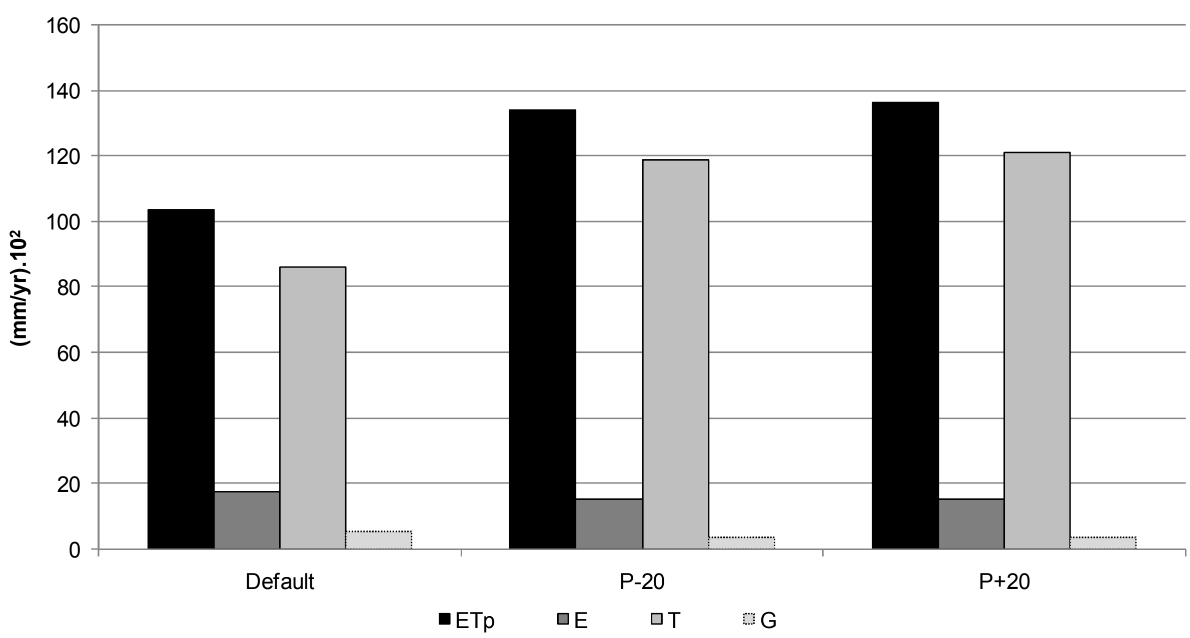


Fig. 6. Observed (Default) and simulated water balance components for scenarios P+20 and P-20

It is important to mention that the simulation did not consider the impacts that deforestation would cause on climatic variables. Although with the results obtained from the simulation, it is possible to conclude that deforestation modifies substantially physical processes of the hydrological cycle.

Impacts are easier to be seen during the rainy season. Furthermore, with less water available for evapotranspiration, the vegetation may suffer from water stress. Although some authors found a precipitation increase in deforested areas (Li et al., 2007), if the deforestation keeps on increasing, the changes in the hydrological cycle might become unsustainable. The change in cover / land use can lead the current system to a new dry equilibrium, and vegetation should be modified to adapt itself to climate changes.

5. Conclusions

Firstly, it was needed to make sure if the model could be used in that region, due to the lack of some meteorological data and the small slope of the region. Based on the NASH, RSR, PBIAS and D% criteria, the results indicate acceptable values. Furthermore, since it is a semi-distributed model, it requires less startup parameters than the distributed models, and also is able to calculate results faster.

Deforestation in Amazonia has been occurring for some decades and the rate of annual growth is noticeable. In addition, this might be influenced by climatic and social-economics factors. Land cover/use changes simulations indicated that the runoff can be changed. The results suggest that there is an increase in runoff when deforestation occurs in the extreme and trend scenarios, associated with less interception of water by the canopy. If the average rate of deforestation continues to be about 3.45% per year in the basin, our simulations predict that the annual runoff will increase about 27% by 2013 and 41% by 2016. Samuel Hydropower, located on the Jamari river, began to be built in 1982. Between 2004 and 2006, the hydropower floodgates had to be opened because the river level reached its maximum level.

The results make us believe that the ongoing deforestation could be responsible for opening these floodgates, since the observed data do not indicate more rain than the average. In used model, sediment load that affects the level increase of the river is not taken into account, but it is likely to result in a sediment increase due to the silt produced by deforestation.

Evapotranspiration and groundwater tend to decrease with deforestation. Results show that the main impact might occur on transpiration, which tends to decrease with deforestation, while the evaporation tends to increase. Alterations in water balance in the Amazon can result in modifications in the local hydrological cycle, and agreeing with other studies, it will affect rain patterns there and close areas, once the water vapor generated goes straight to the neighborhood.

6. References

Brubaker, L.K., Entekhabi, D., and P.S. Eagleson. (1993). Estimation of continental precipitation recycling. J. Climate, Vol. 6, pp. 1077-1089.

de Voogt, K., Kite, G.W., Droogers, P., and H. Murray-Rust. (1999). Modeling water allocation between a wetland and irrigated agriculture in the Gediz Basin, Turkey. Research Report, International Water Management Institute, Colombo, Sri Lanka

Eltahir, E.A.B., and R.L. Bras. (1994). Precipitation recycling in the Amazon basin. Quart. J. R. Met. Soc., Vol. 120, pp. 861-880.

Fearnside, P.M. (2007). Deforestation in Amazonia. Encyclopedia of Earth. Eds. C.J. Cleveland (General Editor) & M. Hall-Beyer (Topic Editor). Environmental Information Coalition, National Council for Science and the Environment, Washington, D.C., U.S.A.

Foley, I.A., Botta, A., Coe, M.T., and M.H. Costa. (2002). The El Niño-Southern Oscillation and the climate ecosystem and river of Amazonia. G. Biogeochemical Cycles, Vol.16, pp.1132-1144.

Kannan, N. et al., (2007). Hydrological modelling of a small catchment using SWAT-2000 – Ensuring correct flow partitioning for contaminant modeling. J. Hydrology, Vol. 3(34) pp. 64-72.

Kite, G.W. (2005). Manual for the SLURP hydrological model. 236 p.

Kite, G.W., and P. Droogers. (1999). Irrigation modeling in the context of basin water resources. J. Water Resources Development, Vol.15, pp. 43-54.

Kite, G.W., Danard, M., and B. LI. (1998). Simulating long series of streamflow using data from an atmospheric model. Hydrological Sciences, Vol.43(3).

Kite, G.W., and P. Droogers. (1999). Irrigation modeling in the context of basin water resources. J. Water Resources Development, Vol.15, pp. 43-54.

Krusche, A.V., Ballester, M.V.R., and R.L. Victoria. (2005). Effects of land use changes in the biogeochemistry of fluvial systems of the Ji-Paraná river basin, Rondônia. Acta Amazônica, Vol. 35(2), pp. 192-205.

Laurent, MESt, C. Valeo. (2003). Modeling runoff in the northern boreal forest using SLURP with snow ripening and frozen ground. Geophysical Research Abstracts, Vol. 5, pp. 06-30.

Li, K.Y., Coe, M.T., Ramankutty, N., and R. Jong. (2007). Modeling the hydrological impact of land-use change in West Africa. J. Hydrology, Vol. 337, pp. 258-268.

Marengo, J.A., (2006a). On the hydrological cycle of the Amazon basin: a historical review and current state-of-the-art. Rev. Brasil. Meteorologia, Vol. 21(3), pp. 1-19.

Marengo, J.A., (2006b). Global Climate Changesand biodiversity efects. 201 p.

Martz, W., and J. Garbrecht. (1999). An outlet breaching algorithm for the treatment of closed depressions in a raster DEM. Computers & Geosciences, Vol. 25, pp. 835-844.

Moriasi, D.N. et al., (2007). Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Vol. 50(3), pp. 885-900.

Nóbrega R.S., (2008). Modeling impacts of deforestation in water resources of river basin Jamari (RO) using data surface and TRMM. D.Sc. Thesis. Federal University of Campina Grande, Paraíba, Brasil. 212p.

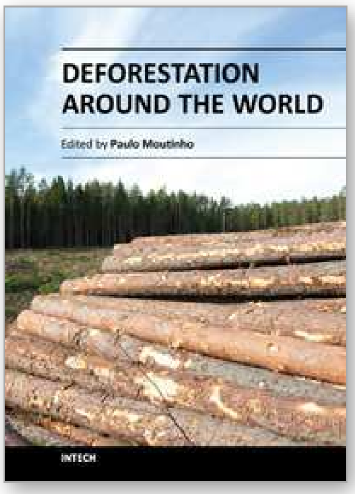
Santos, C. A. (2001). Fronteira do Guaporé. Porto Velho/RO: EDUFRO.

Su, M, Stolte, W.J., and G. van der Kamp. (2000). Modeling Canadian prairie wetland hydrology using a semi-distributed streamflow model. Hydrological Processes, Vol.14(14), pp. 2405-2422.

Thorne R., and M. Woo. (2006). Efficacy of a hydrologic model in simulating discharge from a large mountainous catchment. J. of Hydrol, Vol. 30(1-2), pp.301-312.

Trenberth, K.E. (1999). Atmospheric Moisture Recycling: Role of Advection and Local Evaporation. J. Climate, Vol. 12, pp.1368-1381.

Zhi, L., et al., (2009). Impacts of land use change and climate variability on hydrology in an agricultural catchment on the Loess Plateau of China. J. Hydrology (doi: 10.116/j.jhydrol.2009.08.007)



Deforestation Around the World

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Deforestation and forest degradation represent a significant fraction of the annual worldwide human-induced emission of greenhouse gases to the atmosphere, the main source of biodiversity losses and the destruction of millions of people's homes. Despite local/regional causes, its consequences are global. This book provides a general view about deforestation dynamics around the world, incorporating analyses of its causes, impacts and actions to prevent it. Its 17 Chapters, organized in three sections, refer to deforestation impacts on climate, soil, biodiversity and human population, but also describe several initiatives to prevent it. A special emphasis is given to different remote-sensing and mapping techniques that could be used as a source for decision-makers and society to promote forest conservation and control deforestation.