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Sensitivity test of the Hydrological Model of Large Basins (MGB-IPH) in scenarios of extreme changes in soil use and occupation, precipitation regime and mean air temperature

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ABSTRACT

The Hydraulic Concepts Model Distributed from Large Basins of the Hydraulic Research Institute (MGB-IPH) is a rainfall-type model validated in several basins in South America, including in rivers of the Amazon Basin. The inputs of the model are climatological, rainfall, relief, and soil cover data. The objective of this study is to test the sensitivity of the model in extreme scenarios of soil use and occupation, changes in precipitation and mean air temperature. The case study was carried out in the Curuá-Una river basin, located southeast of Santarém-Pará. The MapWindow-GIS software and the IPH-Hydro Tools plug-in were used in the preprocessing, and the MGB-IPH plugin was processed. The results showed that the MGB-IPH has sensitivity to changes in soil use, precipitation, and mean air temperature. In the sensitivity test of soil use and occupation the results showed that low vegetation and anthropization increase the maximum peaks of flow; In periods of Amazon flood with low rainfall occurrence, the low vegetation scenario has a higher flow rate; And the forest scenery prevents intense floods. In the tests of changes in the precipitation regime, a 50% decrease in rainfall reduced the flow by 32% and a 50% increase in rainfall increased the flow by 218.6%. However, in the tests of increase of the mean air temperature the results did not show significant responses in the flow regime, however, this scenario, added with the increase and / or decrease of the precipitation regime, presented as attenuator for both floods and droughts. Keywords: Hydrological Modeling, Rainfall-flow, Watersheds, Curuá-Una River Basin.

Teste de sensibilidade do Modelo Hidrológico de Grandes Bacias (MGB-IPH) em cenários de mudanças extremas no uso e ocupação do solo e, regime de precipitação e temperatura média do ar

RESUMO

O Modelo Hidrológico Conceitual Distribuído de Grandes Bacias do Instituto de Pesquisas Hidráulicas (MGB-IPH) é um modelo do tipo chuva-vazão validado em diversas bacias da América do Sul, inclusive, em rios da bacia amazônica. As entradas do modelo são dados climatológicos, relevo e cobertura do solo. Pretende-se neste estudo testar a sensibilidade do modelo em cenários extremos de uso e ocupação do solo e, alterações na precipitação e temperatura média do ar. O estudo de caso foi realizado na bacia do rio Curuá-Una localizado a sudeste de Santarém-Pará. No pré-processamento utilizou-se o *software* MapWindow-GIS e o *plugin* IPH-Hydro Tools e no processamento utilizou-se o *plugin* MGB-IPH. Os resultados mostraram que o MGB-IPH possui sensibilidade às mudanças no uso do solo, precipitação e temperatura média do ar. No teste de sensibilidade de uso e ocupação do solo os resultados mostraram que vegetação baixa e antropização aumentam os picos máximos de vazão; em períodos de cheia amazônica com ocorrência de baixa precipitação o cenário vegetação baixa possui maior vazão; e o cenário floresta evita cheias intensas. Nos testes de mudanças no regime de precipitação a diminuição de 50% de chuvas reduziu a vazão em 32% e, o aumento de 50% de chuvas aumentou a vazão em 218,6%. Já nos testes de aumento da temperatura média do ar os resultados não mostraram respostas significativas no regime de vazão, porém este cenário, somado com o aumento e/ou diminuição do regime de precipitação, se apresentou como atenuador tanto para as cheias quanto para as secas.

Palavras-chave: Modelagem Hidrológica, Uso e Ocupação do Solo, Bacias hidrográficas, Testes de sensibilidade.

Introduction

Water is one of the main substances that make life possible. Due to this, historically villages, communities, and cities have developed close to water bodies, micro-river basins or similar (Bindu and Mohamed, 2016; Hommes and Boelens, 2018; Kellogg and Samanta, 2018; Sharma et al., 2019). These developments of cities alter land use and occupation. Studies on the influence of these changes in the flow regime of a river basin can be found in Bayer and Collischonn (2013), and Zeilhofer, Alcantara and Fantin-Cruz (2018). In these types of studies, hydrological modeling is presented as a useful tool to simulate future scenarios in different land uses and climatic variations (Clark et al., 2015; Kauffeldt et al., 2016; Sorribas et al., 2016). There are several hydrological models described in the literature, among them are the SWAT and the Hydrological Model of Large Basins (MGB-IPH) (Pontes et al., 2016; Paz et al., 2018; Brewer et al., 2018; Daggupati et al., 2018). The MGB-IPH is a mathematical model written in Fortran that can be used to represent hydrological processes in watersheds with areas equal to or greater than 10,000 km² (Collischonn et al., 2007). The MGB-IPH is not a commercial product, it is a freeware plugin developed for Geographic Information Systems (GIS) platform, specifically MapWindow 4.x (Fan et al., 2010b). The MGB-IPH has been developed at the Instituto de Pesquisas Hidráulicas (IPH) of the Federal University of Rio Grande do Sul (UFRGS) over the last 15 years. Its structure is based on the LARSIM and VIC-2L models (Collischonn, 2001). In the model, the basin is discretized in square cells which, in turn, are divided according to the characteristics of land use, vegetation cover and soil type. These subdivisions are called blocks (Neto, 2006), but the most current concept, according to Fan et al. (2013), is the Hydrological Response Unit (URHs). In this way, each cell, in turn, is subdivided according to the URH present within its limits.

The MGB-IPH is a model of the rain-flow type where one enters with climatological data, relief, ground cover, and is obtained hydrograph response. Sensitivity tests of the model have been performed by Adan and Collischonn (2013) and Pontes et al. (2017) to analyze output hydrographs in different types of land use and in different climate change scenarios. According to the IPCC

Report (2014), interdisciplinary studies, which combine climatology with soil science and mathematical/computational tools for modeling phenomena linked to global warming, have grown exponentially in recent years. The growing numbers of publications in this regard indicate a concern of man with the magnitude of his interventions in the natural dynamics of the planet. Results of predictive models indicate that anthropogenic actions that generate negative impacts on water resources can cause, in addition to economic and social crises, survival crises in the terrestrial environment (de Moraes et al., 2015; Coelho Welerson and da Siva, 2019), since, depending on the scale of the impact, consequences can occur at a global level, both in the climate and in food production, for example. Thus, there is a need to know the effects of climate change and land use on water resources and estimate them in extreme events, for a better understanding of the interaction between systems. One possibility to perform these studies with high processing is through modeling. These tools allow the generation of rapid information for the foundation of decisions that can mitigate damages and negative effects to the water resource. In this context, the sensitivity tests of hydrological models are important for previous adjustments, understanding of their processing capacities and evaluation of the responses to changes in system parameters.

The objective of this work is to test the sensitivity of the MGB-IPH model in extreme scenarios of changes in soil use and occupation, precipitation regime and average air temperature. The tests were carried out with database and geometry of the watershed of the Curuá-Una river, Santarém, Pará.

Material and methods

Study Area

The watershed of the Curuá-Una River (Figure 1) has an area of approximately 17,351.34 km², a maximum length of 216.08 km and a maximum width of 125.78 km (Jati and Silva, 2017). Soil cover classes are varied, ranging from dense to fully exposed soil. The types of soils vary in Gleissolo, Plintossolo, Neossolo, Argissolo, and Latossolo. However, the latter is predominant and can be found in several parts of the basin, mainly in the vicinity of the Palhão Waterfall, where the

Curuá-Una Hydroelectric Plant (UH Curuá-Una) is maintained and operated by Eletronorte S/A.

Figure 1. Location map of the Curuá-Una river basin. Source: Author's collection.

The climatic characteristics of the region of Curuá-Una, in average terms, are similar with many regions of the Amazon. The air temperature is always high, with the annual average of 25.6 °C and maximum values close to 31 °C and the minimum of 22.5 °C. Regarding relative humidity, it presents values above 80% in almost every month of the year. Rainfall approaches 2,000 mm annually (Junk et al., 1981). In general, the rainy seasons coincide with the months of December to June and the less rainy months, from July to November. The surplus of water in the soil corresponds to the months of February to July, with a surplus of more than 750 mm, with March being the month with the highest value. The lowest values of water in the soil intensify between August and December, being September the month of greatest need, reaching less than 90 mm.

Characterization of Procedures

The sensitivity tests of the model were divided into two groups: "Sensitivity test to changes in soil use and occupation" and "Sensitivity test to changes in

precipitation regime and mean air temperature". Initially, a robust geodatabase was generated for the use of MGB-IPH. In this stage, the Digital Elevation Model (MDE), a product of the Shuttle Radar Topography Mission (SRTM), with a spatial resolution of 90 m, fluviometric data downloaded from the Hidroweb system of the National Water Agency (ANA), pluviometric and climatological data of the Soil and Water Assessment Tool (SWAT), a pedological survey downloaded from the Brazilian Institute of Geography and Statistics (IBGE), LANDSAT 5 images and Mapwindow Software.

The geodatabase was used as input to the routines of the IPH-Hydro Tools algorithm, in Mapwindow Gis, for discretization and production of basin geohydrologic matrices. The coordinate system and Datum used throughout the work was GCS WGS 84. The geo-referenced positions of the fluviometric, pluviometric and climatological station are represented in figure 2.

Figure 2. Map of the location of the fluvimetric station and of the rain and weather stations.

In the calibration and validation phases, the IPH plug-in Hydro Tools, MGH-IPH plug-in, Excel, Fixed Parameters, and Calibrable Parameters were used. These parameters were elaborated based on the studies of Neto (2006), Fan (2011) and de Oliveira et al. (2012). The MapWindow GIS, MGH-IPH plug-in and Calibrable Parameters were used to perform the simulations. Firstly, we calculated the result calculated for model validation as a control scenario (scenario 00), that is, this scenario was calculated to simulate the

actual phenomenology of the flow curve, obtained through data observed at the measuring station 18121006, with the highest fidelity possible. In this work, due to the scarcity of observed data, only one fluvimetric station was used, and this one is located downstream of the dam of the Curuá-Una Hydroelectric Power Plant. After the definition of the control scenario, the scenarios proposed by the sensitivity test group, according to Table 1, were simulated.

Table 1. Scenarios worked on the sensitivity tests of the MGB-IPH organized in two groups of simulations.

1° Group	Changes in land use and occupation
Scenario 1:	100% of medium and high vegetation;
Scenario 2:	100% of low vegetation and agriculture;
Scenario 3:	100% of anthropized areas.
2° Group	Changes in precipitation and average air temperature
Scenario 4:	Decrease of 50% precipitation;
Scenario 5:	Increase of 50% precipitation;
Scenario 6:	Increase of 4 °C;
Scenario 7:	Increase of 4 °C and Decrease of 50% precipitation;
Scenario 8:	Increase of 4 °C and Increase of 50% precipitation.

To measure the quality of the model adjustments in the validation and simulations the objective functions were used: Nash (r^2), Nash log, volume error (ΔV) and percentage of volume error (ΔV (%)). In hydrological modeling, the Nash number

represents the efficiency of the model (Lin, Chen and Yao, 2017; Knoben, Freer and Woods, 2019). This parameter can range from $-\infty$ to 1, when the r^2 value is greater than 0.75, the model's performance is good. When the value is between 0.36 and 0.75

is considered acceptable, and in cases that is less than 0.36 indicate that the simulation is not following the phenomenology studied and corrections should be made.

Other statistical analyzes used were: correlation between the simulations and data observed through the analyzes of the Pearson coefficient of determination (R^2) and the Spearman ρ to evaluate the significance of the differences in the flow regime between the scenarios (de Winter, Gosling and Potter, 2016; Dror et al., 2018). In these tests, the accepted null hypothesis (H_0) was that there is no significant correlation between the scenarios, and the alternative (H_1) that there is a significant correlation between the scenarios (Place reference), at a significance level of 5%, or in the tests, 95% chance for H_0 and 5% for H_1 is given.

Statistical calculations, data tabulation, and graph plotting were performed using software: Excel and R Language Compiler 3.3.2.

The Shapiro-Wilk normality test for the observed and calculated data in the validation showed that the values sampled did not come from a normal population of data.

The results for calculations of objective functions and volume errors in the validation were: $r^2 = 0.53$, $\log r^2 = 0.63$, $\Delta V = -0.06$ and $\Delta V (\%) = -5.84$. These results are considered acceptable for hydrological modeling, mainly in the case of a basin with the modified flow due to the hydroelectric dam operation. In average terms, the validation curve simulated well the flow, however, the data observed have considerable daily flow variations due to the control of the reservoir through the opening and closing of the spillway. Figure 3 (a) shows the oscillation with significant amplitudes along the hydrograph of the observed data. In 3 (b) the dispersion of the calculated data is presented graphically in relation to the observed ones and in 3 (c) is a boxplot to analyze the differences of means and quartiles between the observed flow regime and the calculated flow regime.

Results and discussion

Validation

Figure 3. (a) Validation hydrograms of the model; (b) Linear trend scatter plot; (c) Boxplot for comparison of means at 0%, 25%, 50%, 75% and 100%.

The coefficient of determination in the correlation test was 0.73. This value indicates that the generalized statistical model of linear regression was able to explain with 73% confidence the calculated data in relation to those observed. Spearman's ρ was 0.8 and $p\text{-value} = 2.2\text{e-}16$. These results infer that the alternative hypothesis (H1) is accepted with 95% confidence, that is, to affirm that there is a significant correlation between the values measured at the fluviometric station and the simulated values at the validation stage. The boxplot analysis shows that the amplitudes of the maximum and minimum flow values in the calculated data were smaller than the amplitudes in the observed ones; there were no mean values outside the mean in the calculated or observed data, but there were atypical maximum flow values both in the calculated and in the observed, these values are represented in the graph as outliers, and mean values well above the mean of the maximum values. The most probable cause of this no typicity was the occurrence of a high volume of precipitation occurred in 1982, probably a La Niña.

Considering the acceptable Nash number, correlation and error of volume and that there is no significant difference between the sample populations of the observed data and the calculated data, one can then admit scenario 00 (validation) as control scenario, in other words, as a parameter for analysis of the simulations.

Simulations

1st Group: Sensitivity tests to extreme changes of use and soil occupation.

The scenarios of the 1st group are represented in Figure 4, so as to visually emphasize the extreme changes in the use and occupation of the soil to test the sensitivity of the model to the proposed changes. The control scenario (scenario 00), a product of the classification supervised by verosimilarity of the Curuá-Una river basin based on the LANDSAT image of 1985.

Figure 4. Visual representation of the scenarios proposed in the 1st group of simulations.

The hydrographs of the simulations followed well the phenomenology of the flow regime (Figure 5 (a)), but scenario 03 presented a deviation from the curve for values significantly higher than the control, inferring that the exposed soil increases the flow rate. Figure 5 (b) shows a boxplot graph to evaluate the differences between the minimum, maximum and mean flow rates for each scenario in

relation to the control. It is verified that the average of scenarios 02 and 03 overestimated the average of the control. In all scenarios, atypical points of maximum values occurred, whose main factor is related to the occurrence of the high volume of precipitation occurred in 1982, as discussed previously.

Figure 5. (a) Comparison hydrographs of the phenomenology of the flow regime of the proposed scenarios in relation to scenario 00; (b) Boxplot to evaluate differences between scenarios in 0%, 25%, 50%, 75%, and 100%.

The average and high forest landscape has a Nash (r^2) number close to 1, this fact was already expected because the LANDSAT satellite image used to classify land use and occupation was imagined in 1985, and according to Jati and Silva (2017) in this period, about 83% of the Curuá-Una

basin was composed of medium and high vegetation in clayey and clayey soils, that is, the control scenario has 83% similarity to scenario 01, since the main feature of this scenario is the covering 100% of the basin with medium and high forest.

Table 2 - Objective functions results of the simulated scenarios in relation to the control scenario.

		r^2	$\log r^2$	ΔV	$\Delta V (\%)$	R^2	ρ	p-value
Control	Scenario 01	0.99	1.00	-0.03	-2.95	0.99	1.00	$2.2 \cdot 10^{-16}$
X	Scenario 02	0.61	0.68	0.27	27.11	0.98	0.99	$2.2 \cdot 10^{-16}$
Simulated	Scenario 03	0.54	0.75	0.26	25.85	0.97	0.99	$2.2 \cdot 10^{-16}$

The volume error of scenario 01 in relation to the control was not significant, because even underestimating the reference flow, the underestimation was less than 3%. Differently, the scenarios 02 and 03 presented significant volume errors, overestimating the control in 27.11% and 25.85% respectively. The dispersions of the simulated scenarios in relation to the control scenario (Figures 6 (a, b and c)) showed linear

trend, with values of the Pearson coefficient of determination very close to 1. The results of Spearman's ρ infer that H1 is accepted with 95% confidence, which indicates that the correlations between the scenarios and the control are significant and that in general, there are no significant differences in the flow regimes of the simulated scenarios in relation to the control scenario.

Figure 6. (a), (b) and (c) Scatter plots and linear trend line of scenarios 01, 02 and 03 with respect to scenario 00; (d) Bar chart of the distribution of maximum flows for the scenarios studied between 1979-1985; (e) Bar graph of the distribution of minimum flows for the scenarios studied between 1979-1985; (f) Legend of the graphs (d) and (e).

In Figure 6 (d) is a bar graph of the maximum flow peaks of each scenario worked between 1979 and 1985. These peaks represent the Amazon flood periods, i.e. the rainy season periods of the region. It is verified that in relation to the control scenario, the scenarios 02 and 03 presented higher peak flows during the rainy season. With highlight to scenario 03, this scenario presented the highest

peaks in most of the studied years; it can be seen that the years 1981, 1983 and 1985 were the exception. For these periods, scenario 02 had bigger peaks. According to studies by Sousa et al. (2015), Moura, Vitorino and Adami (2018), and Lee, Yeh and Jo (2019) in 1982-1983 there was a strong meteorological anomaly, one of the largest El Niño recorded in the Pará region; and it is

observed that the years 1981 and 1985 were also periods of low flow, in those years there may have been a deflection of the Pacific heating phenomenon, in 1981 a previous reflection and in 1985 a later reflection (do Vale et al., 2016; Tavares et al., 2018; Coutinho et al., 2018).

Figure 6 (e) shows a bar graph of the minimum flow peaks. These peaks represent the region's ebb, i.e. the dry season. It is observed that the low vegetation and agricultural scenario avoided excessive droughts, in general, throughout the studied period. However, the average and high vegetation scenario presented an underestimation of flow in all years but were not significant, differences were lower than 2.5% in relation to the control scenario. Table 5 shows the behavior of each scenario during the extreme events of La Niña and El Niño in 1982 and 1983, respectively.

Table 5. Comparison of increases and percentage decreases in maximum and minimum flow in relation to the control scenario in the years when floods and ebbing were intense.

	Max Discharge (1982)	Min Discharge (1983)
Scenario 01	↓ 2.8%	↓ 2.7%
Scenario 02	↑ 20.27%	↑ 36.8%
Scenario 03	↑ 25.7%	↑ 6.1%

The arrows down in Table 5 indicate decreasing and upward flow addition in relation to the control scenario. It is verified that during the event of much precipitation, scenarios 02 and 03 presented similar behaviors, increasing the average flow 22.98%, that is, intensifying the floods, however, during the dry season, scenario 02 significantly avoided the decrease of the flow.

In general, the results represent that the medium and high vegetation scenario avoided excessive floods, its hydrograph had behavior very close to the control hydrograph. On the other hand, the anthropogenic scenario and exposed soil, overestimated the maximum flow representing significant flood occurrences. Similar results were found by Blainski et al. (2011) through the SWAT hydrological model. In the aforementioned study, the exposed soil scenario presented the highest

values for average, maximum and minimum flow, in relation to the forest landscape.

The results show that the MGB-IPH model responds well to changes in soil cover characteristics. Similar results are found in Bayer and Collischonn (2013). The objective of the study by Bayer and Collischonn (2013) was to verify the sensitivity of the MGB-IPH to changes in land use and to compare its performance with results of experiments available in the literature. The authors proposed extreme scenarios with 100% forest and 100% pasture, in average terms, similar to the scenarios proposed in this work. In both studies, the results showed that the average flow rates have a strong dependence on the type of soil cover and that when the type of cover is modified, the increase or decrease of the average flow can occur, according to Bayer and Collischonn (2013), is in agreement with the experimental results described in the literature. Classical studies in hydrology corroborate these results, for example, Hibbert (1967 apud Bosch and Hewlett, 1982), verified that the average flow increases as a result of the change of forest to lower vegetation and deforestation. Similar results were obtained by Bruijnzeel (1990) and Lawson et al. (1981). For Blainski et al. (2011), the average flow increase can be attributed to the reduction of soil water infiltration. Several factors can lead to this occurrence, for example, the reduction of rainfall interception by the vegetation can cause damage to the soil surface, sealing it. As a consequence, the runoff is intensified towards drainage lines.

Anaba et al. (2017) used the SWAT model in various land use scenarios and found that The model satisfactorily simulated stream discharge from the catchment. The model performance was determined with different statistical methods. The results showed a satisfactory model streamflow simulation performance. The results of runoff and average upland sediment yield estimated from the catchment showed that, both have increased over the period of study. The increasing rate of runoff can lead to severe and frequent flooding, lower water quality and reduce crop yield in the catchment. Therefore, comprehensive water management steps should be taken to reduce surface runoff in the catchment.

2st Group: Sensitivity tests for changes in precipitation and average air temperature

The sensitivity tests of MGB-IPH to changes in precipitation regime and mean air temperature was performed considering the scenarios 04, 05, 06, 07 and 08, as described in the methodology section. These scenarios were defined in order to consider extreme amplitudes of rain and temperature, both for more and for less, in order to verify the responses of the MGB-IPH to these phenomena. Studies of model sensitivities tests are common in modeling water resources, climate, and global circulation. Oliveira (2012) tested the sensitivity of the WRF / Chem model in variations of concentration of particulate material, its results indicated that the concentration of particulate material has an impact on precipitation formation; Barreto et al. (2013) compared the sensitivity of eight models in relation to the occurrence of seasonal precipitation and the decrease of the temporal scale; and Junior et al. (2016) evaluated the sensitivity of the parameterizations in the WRF model during the rainy season. In the case of sensitivity tests of hydrological models for

variations in temperature and climate, Lelis et al. (2012) and de Andrade et al. (2017) tested the sensitivity of the SWAT model in scenarios of changes of several input variables, their results pointed to the existence of sensitivity, mainly to climate variables and soil use and occupation, and not dependence on the degree of discretization of the basin. Methodologies of scenarios similar to those proposed in this work are found in Pontes et al. (2013) and Silveira (2015), where the authors tested the sensitivity of hydrological models to extreme changes in precipitation values.

The results for the hydrograph simulations for scenarios 04, 05, 06, 07 and 08 are in Figure 7 (a) and the results of the calculations of the objective functions and the volume errors are in Table 6. In Figure 7 (b) we present a boxplot graph to evaluate the differences between the minimum, maximum and mean flows of the simulated scenarios in relation to the control scenario.

Figure 7. (a) Hydrographs of the phenomenology of the flow regime of the proposed scenarios in relation to the control scenario; (b) Boxplot to evaluate differences between scenarios in 0%, 25%, 50%, 75%, and 100%.

Table 6. Objective functions results of the simulations compared to the control scenario.

		r^2	$\log r^2$	ΔV	ΔV (%)	R^2	ρ	p-value
Control Scenarios X Scenarios simulated	Scenario 04	-1.28	0.00	-6.62	-61.79	0.70	0.99	$2.2 \cdot 10^{-16}$
	Scenario 05	-5.13	0.00	0.89	89.31	0.97	0.88	$2.2 \cdot 10^{-16}$
	Scenario 06	0.96	0.00	0.06	6.03	0.99	0.95	$2.2 \cdot 10^{-16}$
	Scenario 07	-1.44	0.00	-0.65	-64.61	0.96	0.95	$2.2 \cdot 10^{-16}$
	Scenario 08	-7.15	0.00	1.09	108.60	0.68	0.88	$2.2 \cdot 10^{-16}$

It can be observed in Figure 7 (a) that the scenarios 05 and 08 overestimated the control hydrograph,

and the 08 presented a significant flow peak in the year in which high precipitation occurred. In the

same figure, it is also verified that the hydrograms of scenarios 04 and 07 were well below the control curve. In average terms, these results can be verified in Figure 7 (b), where the sensitivity of the model to the significant increase of the precipitation volume is observed since the model extrapolated significantly the outliers with respect to the upper limit in scenarios 05 and 08.

The results presented in Table 6 show that in all scenarios it has a significant and positive

correlation, with 95% confidence that this is not due to chance; in scenario 08 only 68% of the data can be explained by the generalized linear adjustment model, unlike scenario 06, in which almost 99% of the data are explained by the linear model.

Figure 8 shows the dispersion and linear adjustment graphs for graphical visualization of the linear trend behavior of the scenarios compared to control scenario.

Figure 8. Scatter plots, generalized linear trend line and the straight line equation for each simulated scenario in relation to the control scenario.

Although all scenarios have significant correlation only in scenario 06, the Nash number represented efficiency in the simulation, but this does not imply that in the other simulations the MGB was inefficient, but rather that for scenario 06 the model

simulated a nearly identical hydrograph to the control, with a volume error of 6%, unlike the other scenarios that presented volume errors with high amplitudes for more or less. This fact is not due to

failures of the model, but its sensitivity to increase and decrease of precipitation.

Figure 9 (a) shows a bar graph of the maximum flow peaks for the scenarios worked for each

analyzed year and Figure 9 (b) a bar chart of the minimum flow peaks.

Figure 9. (a) Distribution of the maximum flows representing the Amazon flood periods; (b) Distribution of the minimum flows chart of the distribution of maximum flows for scenarios 04, 05, 06, 07 and 08 between 1979-1985.

The mean peak flow peaks of each scenario infer that the 50% decrease in precipitation reduced flow by 32%, and the 50% increase in precipitation increased flow by 218.6%. Similar results were found by Pontes et al. (2013) and Silveira (2015). Pontes et al. (2013) found that a 50% increase in mean precipitation in the basin would lead to a 142% increase in average flow while a 50% reduction in average precipitation would lead to an 84% reduction in mean flow. Silveira (2015) used the MGB-IPH to perform simulations with increase and decrease of 30% precipitation. It was observed that the reduction of precipitation culminated in a reduction of 43% in the flow, and the increase in precipitation resulted in an increase of 78% in the flow.

The percentages are not similar because its depend on the specific characteristics of each basin, but the relevance is due to the fact that the intensity of floods in events of higher precipitation is more significant than the intensity of the droughts in events of low precipitation. A possible reason for this is the fact that, as precipitation increases, there is a saturation of the reservoirs represented in the MGB-IPH, with this, the increase in surface flow

tends to increase with increasing rainfall. In contrast, the reduction of precipitation generates less surface runoff, but there is still a contribution due to the base flow resulting from the water accumulated in the soil and underground reservoirs (Pontes et al., 2013; Silveira, 2015).

In the scenarios with an increase of 4 ° C, the tendency of floods to be more significant continued, so that this scenario presented as an attenuator for both floods and droughts. The addition of 4 ° C added with a 50% decrease in precipitation decreased 30% of the flow and an increase of 4 ° C added to the increase of 50% of the precipitation increased 230.7% of the flow.

Although the results for flood intensities are more significant than for droughts, both in extreme cases, similar to those calculated in this study and in the referenced ones, infer that the decrease or increase of the precipitation in 50% in the region of the Curuá- One can cause social, economic and environmental damages, due to the reduction or significant increase of the flow of the river. In social terms, the scenario of significant reduction may lead to a paralysis of the operational activities

of the Curuá-Una Hydroelectric Power Plant, lack of electricity supply to the city of Santarém-Pará, problems with water supply in the countryside and in the city, among others; in economic terms, can lead to the losses of hundreds of families dependent on fish to survive, in addition to the lack of energy supply and water are the starting point for cascading events in local economic activities because, if this happens, many means of production will have to stop their activities; and at the environmental level, this scenario can lead to the lack of dissolved oxygen in the water and, consequently, the mortality of several aquatic species. The scenario of a significant increase of precipitation can generate problems of flooding in communities living along the riverbank and impairment of the structural safety of the Curuá-Una Hydroelectric Power Plant. With these results and the discussions of their meanings for the population of the Curuá- It is possible to verify that effects on the global scale, such as climatic changes, may require relevant adaptations, not only of the human species and its society but also of the fauna and flora existing in all the ecosystems present in the region.

Conclusions

The tests (MGB-IPH) showed that the model responded well to all changes in soil use and occupation and changes in rainfall and climate inputs. The results obtained in simulations of scenarios with extreme changes in land use and occupation indicated that landscapes of medium and high vegetation, in regular seasonal periods, avoid floods and low vegetation and agricultural scenarios, and anthropization and exposed soil, in the seasonal periods the floods. These results infer the importance of regions with medium and high vegetation cover to avoid intense flooding in regions with high soil, residential, low vegetation and agricultural index. Changes in soil cover are inevitable processes of urban development, but if these are carried out on the basis of studies and planning, extreme events can be mitigated, for example, the construction of forests in urban centers and in extensive farming regions may help decrease in floods during periods of high precipitation. The results for simulations of scenarios with extreme changes in precipitation regime and mean air temperature inferred that significant changes in precipitation for both increase and decrease affect the hydrological behavior of a river basin, and for the case of an

increase, the effect is more significant. Such scenarios, if they occur due to changes in the terrestrial climate system, will be impacting societies and environmental systems. Overall, all results obtained in this study were in agreement with results published in the literature. It is intended to carry out in future works simulations of combinations of land use and occupation scenarios and changes in precipitation and mean air temperature.

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