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HYDROLOGICAL MODELLING PARAMETERS TRANSFER OF A HYDROSEDIMENTOLOGYCAL RESPONSE UNIT MAP

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RESUMO – O uso de modelagem numérica para estimar vazão e transporte de água e sedimentos em rios tem sido uma das maiores ferramentas para auxiliar a resolver problemas hidrológicos e hidráulicos em engenharia. Entretanto, com as melhorias realizadas nos modelos hidrológicos para adaptar o seu uso em problemas de engenharia de sedimentos, houve a necessidade de modificar os fatores de influência e calibração desses modelos, como o uso de Unidades de Resposta Hidrológica, melhorando os processos de simulação, como a calibração e validação. Contudo, esse tipo de modificação pode trazer dúvidas em relação a credibilidade do modelo. Dessa forma, este estudo visa avaliar se é possível utilizar um mapa de Unidades de Resposta Hidrossedimentológica, mantendo a qualidade e credibilidade do modelo hidrológico. Os estudos prévios realizados demonstram que o modelo apresentou melhorias utilizando uma validação do tipo "Teste de Proxy de Bacia".

ABSTRACT– The use of numerical modeling of flow and sediment transport in rivers has been applied as a major research tool to explain and resolve river engineering problems. However, with the improvement of the researches, it is necessary to modify the factors of influence, as the Hydrological Response Unit map, using in discretization of the sub-basins, to have better models and improve the processes of simulating, as calibration and validation. But, this kind of change could bring doubt about the credibility of the model. In this context, this work aims to answer if, changing the HRU map, the model maintains its credibility and quality. The previous results presented that there is an improvement when we validate the model with the "Proxy-basin Test".

Palavras-chave – Modelagem hidrossedimentológica; URHSed; MGB.

1. INTRODUCTION

According to Kirchner (2006), models overparameterized with different parameters sets could give almost identical fits in the calibration process, generating the equifinality problem (Beven and Binley, 1992), it means that when we will make simulations with condition changes, the model could give different predictions. This problem can render less utility to a hydrological simulation model for wider hydrological purposes, as water-management decisions or forecast discharge, because the model will synthesize data on which a decision should be based, however in reality, the model could not be believed at all (Klemes, 1986).

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Some conceptual models in hydrology, as SWAT (Arnold *et al.*, 1998), uses Hydrological Response Units (HRU) to discretize the watershed and calibrate the model. The HRU represents the factors that influences mostly the hydrological processes (Xu *et al.*, 2012). With the increase of the sediment problems (Chen *et al.*, 2011; Magris *et al.*, 2019) in the watersheds, it was necessary to improve hydrological models to adapt to hydrosedimentological research. Some works (Buarque, 2015; Fagundes, 2018; Rossoni, 2018) using hydrological factors to estimate sediment information from models pointed to the need to use a new HRU map, which the parameters would be focusing in the sediment model calibration.

However, changing the HRU map changes the model parameters and can even increases the number of parameters. These modifications could lead to a greater equifinality problem. In this context, Klemes (1986) create a methodology to demonstrate if the model maintains its good performance, before being operational, with a verification scheme, that could bring credibility to the hydrological, and further hydrosedimentological, modeling and research.

Therefore, this discussion encourages the following questions: Changing the Hydrological Response Unit map, focused in hydrological modeling, to a Hydrosedimentological Response Unit map, focusing on hydrosedimentological modeling, is it possible to maintain the quality and credibility of the hydrological simulations? This paper aims to answer it, since the hydrological modelling is a very important previous step of hydrosedimentological simulations

2. MATERIALS AND METHODS

We used the hydrological large-scale model MGB (*Modelo de Grandes Bacias*), developed by Collischonn, *et al.* (2007), which estimates streamflow from precipitation data and climatic information (Lopes, *et al.*, 2018). This model has been widely evaluated in South America, in works which developed hydrological forecasting systems (Fan, *et al.*, 2016), a modified version of the model which evaluate water quality (Fan, *et al.*, 2015), decision support systems (Pereira, *et al.*, 2012) and land use analysis (Bayer and Collischonn, 2013). The MGB-SED is the hydrosedimentological version of the MGB model, developed by Buarque, *et al.* (2012) and Buarque (2015), and recently applied by the works of Fagundes *et al.* (2019), Föeger *et al.* (2018), Rossoni (2018) and Rossoni *et al.* (2018).

The new watershed discrimination, an Hydrosedimentological Response Units map (HRUSed), was done according to the soil texture and land use combined information maps, according to this paper and the methodology presented in Rossoni and Fan (2019). This approach was chosen because the MGB-SED uses the MUSLE (Williams, 1975) equation (Eq. 1) and one of the MUSLE parameters of calibration is the soil erodibility factor (K). To calculate the K factor, we use soil texture information.

$$SED_{i,j}^{k} = 11.8 \cdot \left(Dsup_{i,j}^{k} \cdot qpico_{i,j}^{k} \cdot Apm_{i,j}^{k}\right)^{0.56} \cdot K_j \cdot C_j \cdot P_j \cdot LS_{i,j}^{k} \cdot FG_j \qquad (1)$$

where, SED [t] is the sediment yield; Dsup [mm/ha] is the volume of runoff; qpico [m3/s] is the peak runoff rate; Apm [ha] is the pixel area; K [0.013.t.m2.h/(m3.t.cm)] is the soil erodibility factor; C [-] is the vegetative cover factor; P [-] is the erosion control practice factor; LS [-] is the length-slope factor; FG [-] is the thick fragments or rocks factor; i and j [-] are factors that indicates the small catchment and the HRU/HRUSed, respectively; and k [-] is the calculate pixel.

To develop the HRUSed map, we used soil texture maps from South America (FAO), from Brazil and Argentina. The land use and cover map used was from GlobCover Portal. The Table 1 synthesizes the data.

Table 1. Data used to develop the Hydrosedimentological Response Units map

Data	Scale/Grid Spacing	Source	Year
Soil Texture base map to the South America	1:5.000.000	FAO Soil Texture Map (BATJES, 2005)	1998
Soil Texture base map to Brazil	1:250.000	IBGE Downloads (IBGE, 2018)	1970-1985
Soil Texture base map to Argentina	1:500.000; 1:1.000.000	GeoINTA (INTA, 2013)	1990
Land use and cover map to South America	300 m	ESA GlobCover 2009 (ESA, 2018)	2009

The Figure 1 presents the study area chosen to validate the HRUSed map, the Hydrologic Rio Grande do Sul Region, Brazil in South America. This area has a great economic, environmental and social importance (Rossoni, 2018; Lopes *et al.*, 2018) to the region. Besides, the area is affected by erosive processes, sometimes positively, as the growth of the economy with the sand, silt and clay mining, sometimes negatively, such as soil erosion and consequent removal of the soil fertile layer, that harms crop production, as high turbidity in rivers and lakes, that harms the intake pipe of the water treatment station, as the high dredging costs. There are 30 sub basins of calibration in the region of interest. It was used observed data from gauge stations from ANA (*Agência Nacional de Águas/Brazil*).

The model validation was based in the Klemes (1986) “Hierarchical scheme for systematic testing of hydrological simulation models”. The tasks are ordered according to their increasing complexity. In this scheme, two major categories are proposed for the process to be simulated:(1) Stationary conditions, and; (2) Nonstationary conditions. Both categories are subdivided into two hierarchical subgroups: (a) The same station (basin) which was used for calibration, and; (b) A different station (basin).

In this work, we used the “Proxy-basin Test”, that is the stationary conditions in a different basin, with different gauge station (1b). This is the basic test for geographical transposability of a model. If a streamflow in an ungauged basin (C) is to be simulated, we need to select two another basin (A and B) in the same region. Then, we calibrate the model in the basin A and validate in the basin B and vice versa. If the two validations results are acceptable and similar, the model could be considerate with a basic level of credibility and with the possibility of estimate streamflow in a basin C adequately.

In this previous study to validate the model, we calibrated the Taquari-Antas River Basin, highlighted in the Figure 1. Then, we used the parameters found in the Taquari-Antas River Basin to simulate all the study area and verify the possibility of transposability between the regions. The Table *2* presents the parameters used before calibrating the hydrological model (1) and the parameters found after the calibration to the Taquari-Antas River Basin, and used to simulate all the study region (2). The Table 3 presents the parameters that are common among the HRUSed, before and after the calibration. In Collischonn *et al.* (2007) the parameters are detailed.

Table 2. Soil parameters calibrated in the Taquari-Antas River Basin and used as transposability of parameters

Hydrosedimentological Response Units	**Soil Storage Capacity**		**Relationship form between storage and saturation**		**Base flow control**		**Interflow control**		**Interflow curvature**	
	Wm[1]	**Wm[2]**	**b[1]**	**b[2]**	**Kbas[1]**	**Kbas[2]**	**Kint[1]**	**Kint[2]**	**XL[1]**	**XL[2]**
Cropland in Sandy Soil	500	350	0.12	0.08	1.00	0.80	10	10	0.69	0.67
Cropland in Medium Soil	250	80	0.12	0.01	1.00	0.15	10	25	0.32	0.67
Cropland in Clay Soil	100	125	0.12	0.08	1.00	0.35	10	12	0.17	0.67
Grassland in Sandy Soil	500	350	0.12	0.08	1.00	0.85	10	10	0.69	0.67
Grassland in Medium Soil	250	100	0.12	0.04	1.00	0.25	10	14	0.32	0.67
Grassland in Clay Soil	100	150	0.12	0.09	1.00	0.85	10	7	0.17	0.67
Forest in Sandy Soil	500	350	0.12	0.11	1.00	0.75	10	10	0.69	0.67
Forest in Medium Soil	250	82	0.12	0.02	1.00	0.28	10	13	0.32	0.67
Forest in Clay Soil	100	75	0.12	0.10	1.00	0.47	10	20	0.17	0.67
Flooded Areas/Wetlands	20	70	0.12	0.07	1.00	0.73	10	10	0.60	0.67
Semi-Waterproof Areas	10	60	0.12	0.07	1.00	0.55	10	10	0.60	0.67

[1] Parameters used before calibrating the model; [2] Parameters from Taquari-Antas calibration and used in all region

To evaluate the model, we used the efficiency metrics: Pearson’s Correlation Coefficient (r), Nash-Sutcliffe Efficiency (NSE), Nash-Sutcliffe Efficiency applied to the logarithm (NSELog), Kling-Gupta Efficiency (KGE) and Percent of BIAS (BIAS). The Table 2 present the range of values and colors considered in this paper to evaluate the model. These values are based in Moriasi *et al.* (2015) and Thiemig *et al.* (2013).

Table 3. Common parameters for all HRUSed

Surface flow shape		**Interflow shape**		**Baseflow shape**	
CS^1	**CS^2**	**CI^1**	**CI^2**	**CB^1**	**CB^2**
10	25	100	100	2000	2200

^{1} Parameters used before calibrating the model; ^{2} Parameters from Taquari-Antas calibration and used in all region

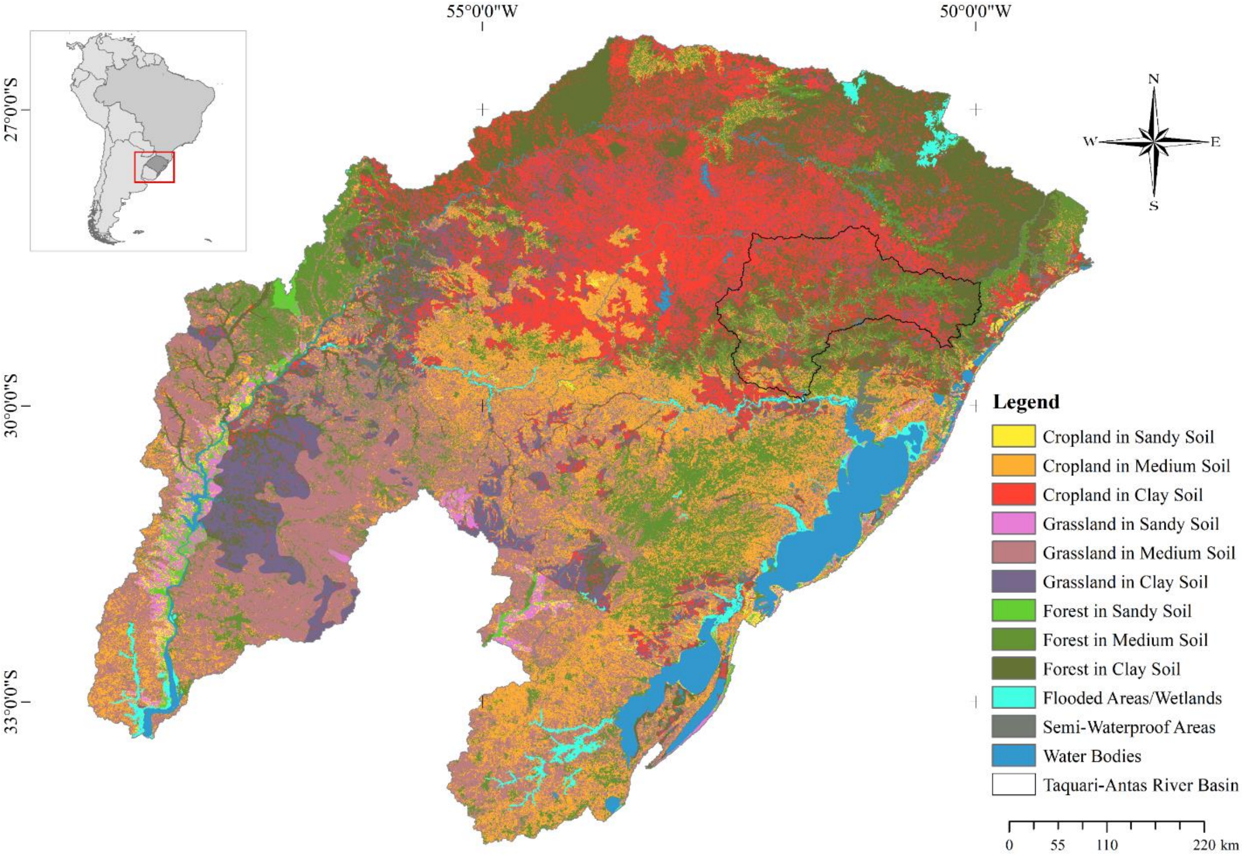


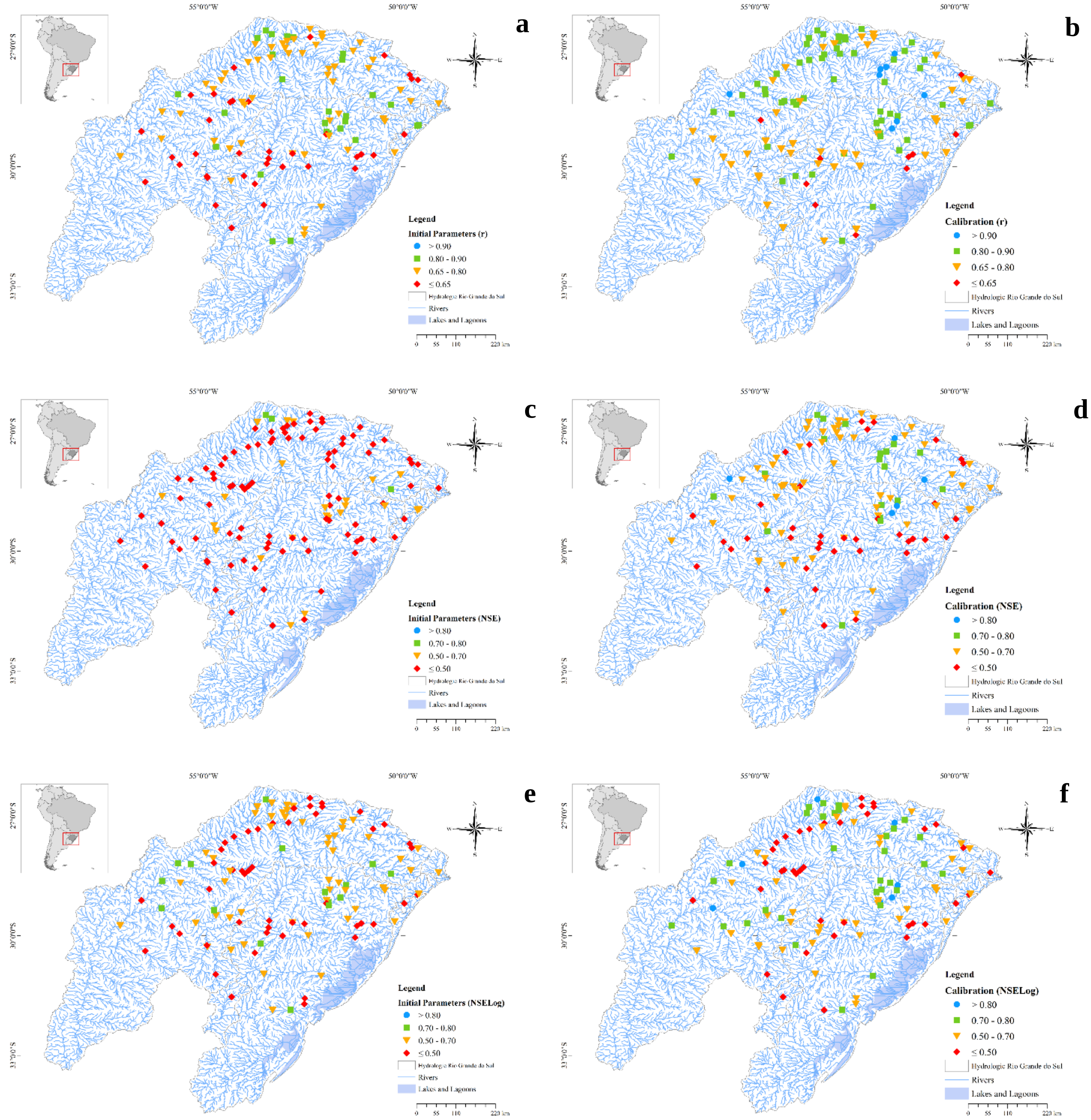
Figure 1. Hydrosedimentological Response Units map to the Hydrologic Rio Grande do Sul used in the simulation; the watershed highlighted with a black contour is the Taquari-Antas River Basin

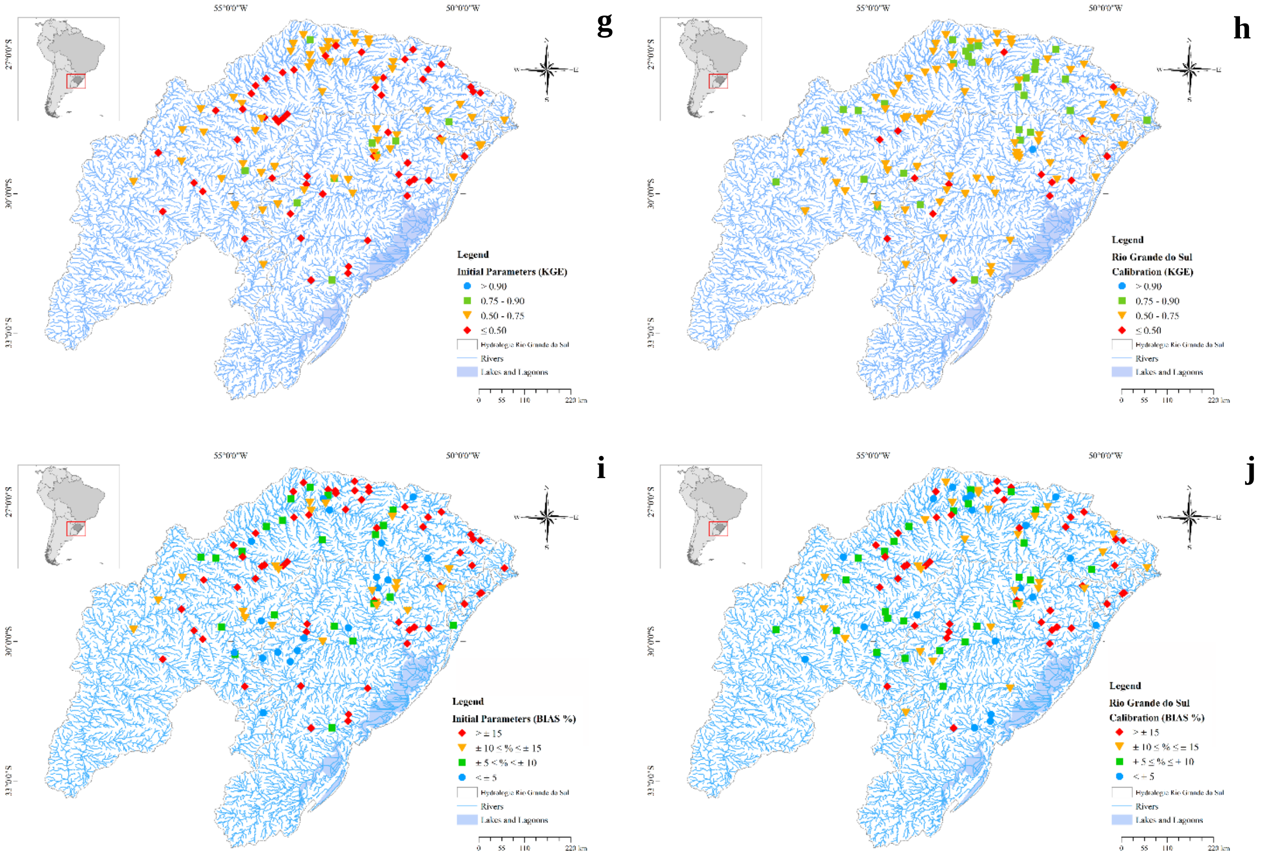
Table 4. Efficiency metrics range of evaluation

Efficiency Metric	**Color/Values Range**			
	Blue	**Green**	**Orange**	**Red**
r	> 0,90	0,80 < R^2 ≤ 0,90	0,65 < R^2 ≤ 0,80	≤ 0,65
NSE NSELog	> 0,80	0,70 < NS ≤ 0,80	0,50 < NS ≤ 0,70	≤ 0,50
PBIAS (%)	< ± 5	± 5 ≤ % ≤ ± 10	± 10 ≤ % ≤ ± 15	≥ ± 15
KGE	> 0,90	0,75 < KGE ≤ 0,90	0,50 < KGE ≤ 0,75	≤ 0,50

3. RESULTS AND DISCUSSIONS

In the Figure 2, it is possible to verify the results synthesized. The first column (a) presents the values of the efficiency metrics before the validation test and the second column (b) present the values after the validation test.





(a) **Initial parameters** of the model; (a) Pearson's Correlation, (c) Nash-Sutcliffe Efficiency, (e) Nash-Sutcliffe Efficiency to the logarithm, (g) Kling-Gupta Efficiency, (i) Percent of BIAS.

(b) **Calibration parameters** of the model; (b) Pearson's Correlation, (d) Nash-Sutcliffe Efficiency, (f) Nash-Sutcliffe Efficiency to the logarithm, (h) Kling-Gupta Efficiency, (j) Percent of BIAS.

Figure 2. Model evaluation to the initial parameters and to the calibrated model with validation

Following the results presented in the maps, we can see that there was an improvement in the model to the study area, after the use of parameters that were calibrated to the Taquari-Antas River Basin. These parameters were generalized to each HRUSed to every small watershed of calibration, this means that the calibration using the MGB model (Collischonn *et al.*, 2007) was generalized in each HRUSed. This differs from SWAT model (Arnold *et al.*, 1998), for example, since in this model the calibration is unique for each HRU and each small watershed, so this HRU is more specific and consequently the calibration also. The variation of the parameters in each standard HRU can compensate the differences between the hydrological processes, questioning the generalization of the parameters in basins without gauge stations.

Using the parameters from the Taquari-Antas River Basin to all study area the quantity of points which presented highest values for the efficiency metrics have increased when compared with the simulation with initial parameters in the study area. This shows that the HRUSed map, even focusing in hydrosedimentological simulation, could be used in hydrologic models, as well as the HRU map, focusing in hydrologic simulations. The advantage of use the HRUSed map is the possibility of a better calibration of the hydrosedimentological model, without losing the quality of hydrological simulation, commonly obtained using an HRU map.

In general, the average values to the study area with the initial parameters was 0.70 (r), 0.14 (NSE), 0.42 (NSELog) and 0.49 (KGE). After the use of calibration parameters, the average of metrics was 0.79 (r), 0.53 (NSE), 0.44 (NSElog) and 0.64 (KGE), respectively. This shows that the transposition of parameters could improve the model performance, giving greater credibility to use the map to hydrological modeling and even the transposition of parameters.

The efficiency metric that presented the best performance was the NSE, before using the calibration parameters, only 3 gauge-stations presented values greater than 0.70. Besides that, 91 gauge-stations presented values less than 0.50. After using the calibration parameters, the values greater than 0.70 was 24 points and values lower than 0.50 went from 91 gauge-stations to 38.

The Person's Correlation (r) demonstrated a great improvement as well, with values greater than 0.80 in 47 gauge-stations before and after went to 86 points. This could be happened because the Taquari-Antas River Basin has very similar characteristics with the north of the study area. In this way, an improvement in this region could cause an improvement in the north of the region of study, which are mostly bedside basins, affecting most of the region of interest. In the north region happened the greater improvement of the model.

However, in the south of the study area we could observe that occurred an improvement, mostly in the efficiency metrics r, NSE and KGE. This represent that, even in areas where there is not a great similarity between the characteristics, even in these cases the use of calibrated parameters is better than the initial parameters from the model. Finally, the BIAS was the efficiency metric that presented the smallest improvement in the performance.

We found better results by generalizing the parameters from Taquari-Antas River Basin to all the Hydrologic Rio Grande do Sul region. However, these results could be improved using different parameters for each HRUSed in each sub-basin of calibration, which is the most used methodology when the watershed have gauge stations.

4. CONCLUSIONS

This work evaluated the performance of a hydrological model, changing the calibration parameters and basin discretization from factors that represents hydrologic processes (Hydrological Response Units) to factors that represents hydrosedimentological processes (Hydrosedimentological Response Units). To evaluate the model, we used the validation test "Proxy-Basin Test", that analyzed the geographical transposability of the parameters of a hydrological model.

The results presented an improvement in the model performance of the study area after used parameters that were calibrated in a sub-basin of the region. This could demonstrate that, when using the HRUSed with the MGB, it is possible to use parameters from a calibrated sub-basin in the watershed in another sub-basin without gauge stations. This can be done without compromising a better performance of the model, as well as using an HRU map.

Besides that, this validation could present a greater credibility to the HRUSed map, demonstrating that even when using a discretization focused on hydrosedimentological modeling, it is still possible to obtain coherent performances to hydrological modeling. Finally, this validation could help to increase confidence in the model to extra-hydrological purposes, as water-management, forecast discharges and hydrosedimentological modeling.

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