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ENGENHARIAS

Influence of multiple water uses on an cross-border watershed in South America

Influência dos múltiplos usos da água em uma importante bacia hídrica transfronteiriça da América do Sul

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ABSTRACT

Knowing water behavior of water, such as flow and level in a watershed is extremely important to manage its multiple uses adequately. One of the models that has been highlighted by several studies and strategies to diagnose and understand hydrological processes and, consequently, define multiple water uses, is the Large Basin Model (MGB). The Mirim-São Gonçalo watershed (MSGW), which is a cross-border basin that stretches over the extreme south of Brazil and northeastern Uruguay, has significant environmental, economic, political and social importance to the population that lives there. This study aims at applying the distributed MGB to

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the MSGW to describe hydrodynamic processes and fluctuation resulting from water levels by considering input and output in the system, natural and anthropic ones, based on the Water Exploitation Index (WEI) and the Water Commitment Index (WCI). Results show that the adapted MGB enabled to simulate hydrological-hydrodynamic characteristics in the MSGW when information on winds were inserted. Results of the Brazilian part of the basin were better supported due to the distribution of input data. Regarding multiple uses, both the WCI and the WEI clearly show that the Uruguayan part of the basin is in a comfortable situation, in contrast with the Brazilian part, which needs special and criterial care since its situation is more critical.

Palavras-chave: *Water Resources; Hydrological Modeling; Hydrical Stress; WEI; WCI.*

RESUMO

O conhecimento do comportamento da água na bacia hidrográfica é de extrema importância para um manejo adequado dos seus usos múltiplos. Um dos modelos que se destaca, em diversos estudos e estratégias, para diagnosticar e entender os processos hidrológicos e, consequentemente definir os usos múltiplos da água é o Modelo de Grandes Bacias (MGB). A Bacia Hidrográfica Mirim São Gonçalo (MSGW) é uma bacia transfronteiriça, localizada no território compreendido entre o extremo sul do Brasil e a porção nordeste do Uruguai com significativa importância ambiental, econômica, política e social para a população que nela vive. O presente estudo objetiva aplicar o modelo distribuído MGB, na MSGW para descrever os processos hidrodinâmicos, as flutuações decorrentes dos níveis de água, considerando as entradas e saídas no sistema, natural e antrópico, a partir do Índice de Retirada de Água (WEI) e Índice de Comprometimento Hídrico (WCI). Os resultados evidenciam que o modelo MGB adaptado possibilitou simular as características hidrológicas-hidrodinâmicas na MSGW quando inseridas informações de vento, destacando melhor suporte dos resultados à porção brasileira da bacia, devido a distribuição dos dados de entrada. Com relação aos usos múltiplos, fica evidente através do WCI e WEI que a porção uruguaia da bacia se encontra em uma situação confortável, o que não ocorre na porção brasileira, que necessita de um cuidado especial e mais criterioso, pois apresenta uma situação mais crítica.

Keywords: Recursos hídricos; Modelagem Hidrológica; Estresse Hídrico; WEI; WCI.

1. INTRODUCTION

The hydrological models are tools developed to represent hydrological processes in large and small-scale basins (Suekame et al., 2021). Its use has been effective not only in studies of effects of climate changes and use of soil but also in analyses of water availability, decision-making processes (Viola et al., 2009; Santos et al., 2013; Fan; Collischonn, 2014; Viana et al., 2018; Niquini et al., 2019) and investigations into propagation of river discharge and its effects (Pontes, 2011; Fan et al., 2014, Munar et al., 2018; Possa et al., 2022).

One of the models that has been highlighted by several studies is the Large Basin Model (MGB), which is a distributed hydrological-hydrodynamic model – applied to large hydrographic basins (greater than 10,000 km²) – that uses the most common data available in most Brazilian states, such as rainfall, air temperature, relative humidity of air, wind velocity and direction, insolation and atmospheric pressure, and enables to calculate discharge of rivers that belong to a certain watershed (Collischonn et al., 2007; Pontes et al., 2015).

Studies using the MGB were presented for several locations: Brito Neto et al. (2021), who employed different land use and occupation scenarios for the Rio Pardo watershed; Oliveira et al. (2016), for

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the Alto Teles Pires watershed, MG; Meller et al. (2012) on the Piracicaba River; Can et al. (2022) for the Mirim-São Gonçalo watershed considering the influence of wind; Fan and Collischonn (2014) for the Ijuí River watershed, RS; Lopes et al. (2015) for Patos Lagoon, RS; Fleischmann et al. (2015) in the Taquari-Antas River watershed, RS and Pontes et al. (2015) for the Araguaia River watershed, Suekame et al. (2021) who used a model in the Alto Taquari watershed with the aim of testing a combination of future scenarios of climate change, land use and occupation, in order to detect changes in hydrological variables; and Vergasta et al. (2021) who evaluated the water balance in the Madeira River watershed using the MGB and the Eta regional climate model.

The Mirim-São Gonçalo watershed (MSGW), which stretches over the extreme south of Brazil and northeastern Uruguay, is an important cross-border basin, which has a shared water regime. It is considered one of the most important freshwater lagoons in Brazil and in Latin America. It ranks second after the Patos Lagoon, where its waters run to, through the São Gonçalo channel, and then flow into the Atlantic Ocean (Fernandes et al., 2021).

Among the highlights in the influence on the water levels of this system, is the wind. This influence was discussed in several studies for regions, such as the Guaíba River and the Patos Lagoon - water sources connected to the Mirim Lagoon and the São Gonçalo Channel - which form a water system with a very low slope, in which the shear stress in the water surface can cause changes in the regime - water level, depending on the intensity and direction of the wind (Castelão and Möller Junior, 2003; Cavalcante and Mendes, 2014; Lopes et al., 2018; Távora et al., 2019, Possa et al., 2023).

Water resources that originate in sources of the MSGW are important to several activities. According to Steinke and Saito (2008), in the MSGW, there are conflicts over the use of water in grain production, mainly rice, and cattle raised for meat to supply national and international markets, the main activity in the Uruguayan part of the basin. In order to mitigate conflicts over multiple uses and conservation of the Mirim Lagoon nowadays, in the Brazilian part of the basin, grant to use water from the Mirim Lagoon for irrigation has been based on the average of levels measured by linimetric rulers located in *Santa Isabel do Sul*, in *Arroio Grande* and in the port in *Santa Vitória do Palmar*, both in *Rio Grande do Sul* (RS) state. Water may be used when the average value of the level between both spots is either equal or above 0.5 m (ANA, 2016).

Therefore, hydrological-hydrodynamic modeling appropriate to the MSGW is important due to the wide range of data on the basin. Through it, which is able to express different scenarios, comprehensive hydrological diagnosis, ground for effective planning and decision-making processes in all activities that require water use. This is based, not only based on the MGB, but also on the Water Commitment Index (WCI) and the Water Exploitation Index (WEI). With that in mind, the present study aims to assess the situation of multiple uses of water in MSGW, through WCI and the WEI, in order to enable watershed managers to make such a study a tool for shared water management cross-border MSGW.

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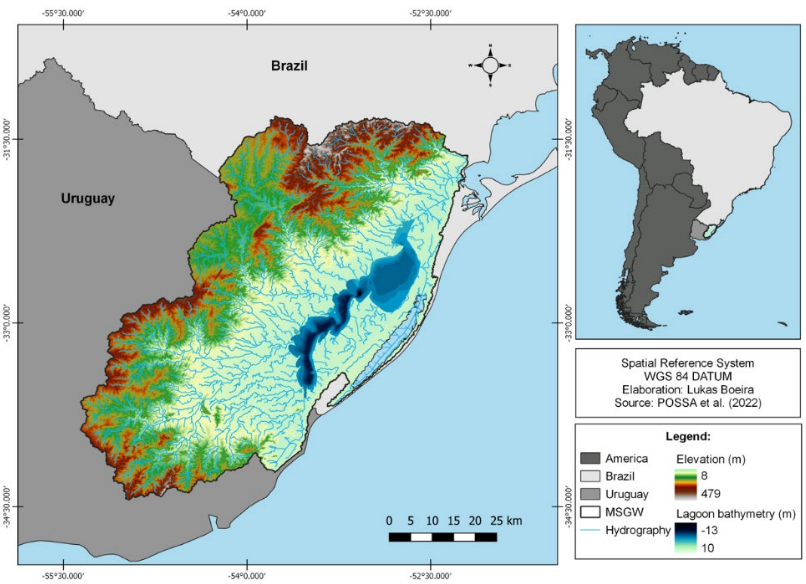
2. MATERIAL AND METHODS

2.1 STUDY AREA

This study was carried out in the MSGW (Figure 1), a cross-border basin located between Brazil and Uruguay. Its geographic coordinates are 31º30′ to 34º35′ South and 53º31′ to 55º15′ West. It stretches over about 62,250 km^2, i. e., 29,250 km^2 (47%) in Brazil and 33,000 km^2 (53%) in Uruguay. Its main water resource is the Mirim Lagoon, whose superficial area is 3,750 km² (2,750 km² in Brazil and 1,000 km² in Uruguay) and whose width may reach about 20 km in some stretches (Fernandes et al., 2021).

It should be emphasized that the MSGW is important to the whole region where it lies, in both Brazil and Uruguay. In the Uruguayan territory, it stretches over 16% of the country, where 5% of the population lives; it means 154,699 inhabitants who live in the urban (92%) and rural (8%) areas. It should be highlighted that 70% of its superficial area is used for agriculture, mainly irrigated rice, and livestock farming (Mvotma, 2017).

Figure 1 - Location of the study area.



Regarding the climate in the region, average monthly rainfall ranges from 103 mm (average recorded every December between 1971 and 2020) to 150 mm (every February in the same period). Annual average is 1,399 mm while reference evapotranspiration ranges from 36 mm (June) to 150 mm (December) and annual average is 1,080 mm (BOEIRA et al., 2021). In the Köppen climate classification, climate in the region is classified as "Cfa", i. e., humid temperate, with hot summers and well-distributed rainfall throughout the year (Peel; Finlayson; Mcmahon, 2007).

2.2. LARGE BASIN MODEL (MGB)

Modeling in the MGB followed a pre-established plan, which was introduced by Alves et al. (2020), who use IPH-Hydro Tools in data pre-processing which is carried out by the free software program SIG Quantum GIS (QGIS). During this pre-processing step, the basin is subdivided into smaller units, called mini-basins, based on the discretization of the drainage network into stretches of constant

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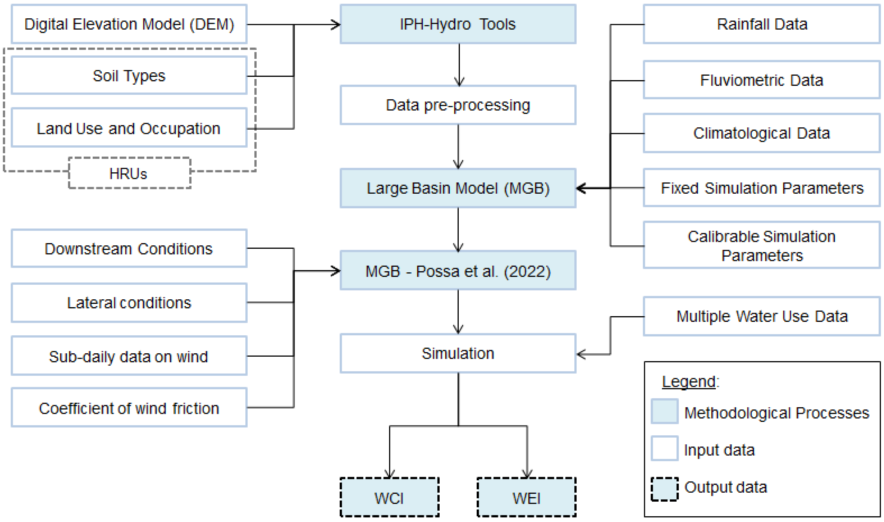
length, being adopted here 10 km. Thus, the size of mini-basins is limited to this length and the minimum number of cells that drain to the point where the network begins to be drawn.

The first modeling was conducted by the traditional model and then the MGB adapted by Possa et al. (2022) was applied. Besides information collected by the traditional MGB, it includes downstream conditions, lateral connections, influence of wind velocity and direction and coefficient of friction. The methodological process of this study took place according to the flowchart shown in Figure 2.

Figure 2 - Methodological process of the study.



2.2.1. INPUT DATA

Firstly, the Digital Elevation Model (DEM) of the Shuttle Radar Topography Mission (SRTM), which has a spatial resolution of 90 m (FARR et al., 2007), was used to collect information on the relief of the MSGW. Studies carried out by the MGB adopt DEM the same resolution, as those with more refined resolutions may need more processing time and prevent IPH-Hydro Tools from working. However, since the study area exhibits flat areas in the DEM, it is necessary to determine the drainage system that enables the connection between the Mirim Lagoon and the São Gonçalo channel which represents the hydrography found in the region and passes through the middle of the MSGW. Therefore, the DEM adapted by Possa et al. (2022) (Figure 1) was used. The authors interpolated bathymetric data after digitalizing the directory of hydrography and navigation issued by the Brazilian Navy into the DEM of the SRTM through a map operation. The SRTM model is subtracted from the interpolation, which results in negative altimetry values that represents the areas of the lagoons in the DEM, considering that the altimetry value of the SRTM was zero. Thus, it was used for generating information on the flooded area and quotas of water levels in every mini-basin. Since the MGB discretizes the basin into mini-basins based on the drainage system and may not use negative values of bedding, in order to avoid processing errors in IPH-Hydro Tools in the future, 20 m was added to the DEM. Thus, all cells became positive and compensated for stream burning in the lagoon resulting from the insertion of bathymetry.

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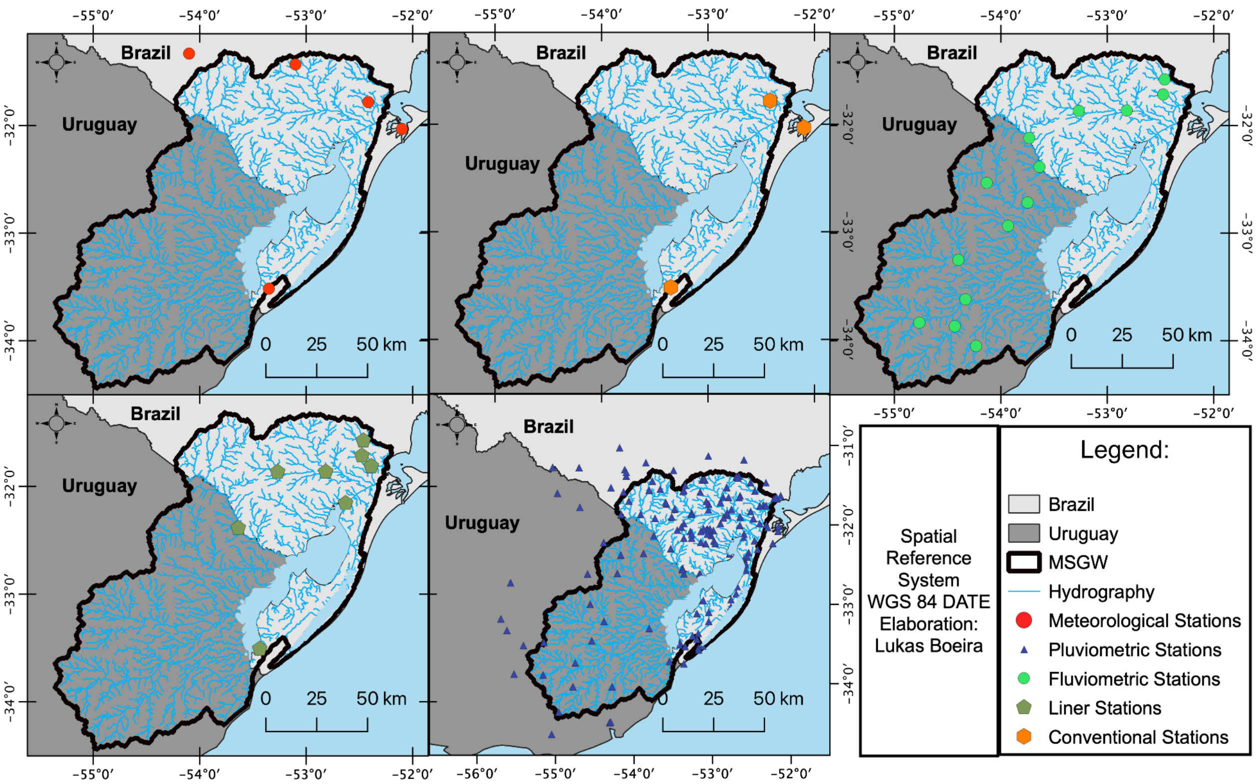
Information on soil and land use in the basin was collected with the use of the map of hydrological response units (HRUs) developed by Fan et al. (2015) in South America, where every HRU has distinct hydrological behavior, which directly affects hydrological processes simulated by the model. This map was developed using databases of different resolutions, with preference given to those with better resolution for the composition of the final map, due to their greater detail.

Hydrometeorological input data used by the MGB (Figure 3) were provided by 158 rainfall, 15 fluviometric and 9 meteorological stations in the study area. Twenty-six rainfall stations and 9 fluviometric ones are controlled by *the Instituto Nacional de Meteorologia do Uruguai* (INUMET) while the other data come from the national hydrological system which is in charge of the *Agência Nacional de Águas e Saneamento Básico* (ANA).

Figure 3 - Location of rainfall and fluviometric, used liner and conventional stations with sub-daily data on wind stations.



Fixed simulation parameters refer to the vegetation and are associated with vegetation found in every HRU of the MSGW. Parameters defined for the simulation are albedo, leaf area index, vegetation height and superficial resistance in good conditions of soil humidity (Alves et al., 2020). This study used values proposed by Possa et al. (2022). Table 1 presents the input parameters used.

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Table 1 – Input parameters used in the MGB.

Parameters	Source
Digital Elevations Model (DEM)	Possa et al. 2022
Soil Types	HRUs - Fan et al. 2015
Land Use and Occupation	HRUs - Fan et al. 2015
Rainfall Data	*Instituto Nacional de Meteorologia do Uruguai* (INUMET) and *Agência Nacional de Águas e Saneamento Básico* (ANA)
Fluviometric Data	*Instituto Nacional de Meteorologia do Uruguai* (INUMET) and *Agência Nacional de Águas e Saneamento Básico* (ANA)
Climatologial Data (air temperature, relative humidity of air, wind velocity, atmospheric pressure and insolation)	*Instituto Nacional de Meteorologia* (INMET)
Fixed Simulation Parameters (albedo, leaf area index, vegetation height and superficial resistance in good conditions of soil humidity)	Possa et al. 2022
Downstream Conditions	Agency for the Development of the Mirim Lagoon Basin (ALM)
Lateral Conditions	Possa et al. 2022
Sub-daily data on Wind	*Instituto Nacional de Meteorologia* (INMET)
Coefficient of Wind friction	Possa et al. 2022
Line Data	Agency for the Development of the Mirim Lagoon Basin (ALM) and *Agência Nacional de Águas e Saneamento Básico* (ANA)

Determination of calibration parameters was based on variables found in HRUs; they were altered to reach the best calibration values (Nash-Sutcliffe coefficient of flow logarithms - NSLog and Relative Volume Error - EV). Besides, data on levels were provided by 9 linear stations in the MSGW (Figure 2): 5 stations were supplied by the Hidroweb system (*Cerro Chato, Passo dos Carros, Pedro Osório, Picada da Areia* and *Cordeiro de Farias* Bridge) while 4 of them were obtained from the *Agência para o Desenvolvimento da Bacia da Lagoa Mirim* - ALM (São Gonçalo Channel Dam and its lock – Upstream - SGCDL-U), São Gonçalo Channel Dam and its lock - Downstream - SGCDL-D), *Santa Isabel do Sul* and *Santa Vitória do Palmar*). Table 2 shows information with their codes and locations.

As shown in Table 2, the vast majority of stations have measurements in the period between 1980 and 2020, with the exception *of Pedro Osório, Santa Isabel do Sul* and *Santa Vitória do Palmar*. Thus, due to the non-existence data from these stations in 49.4% (*Pedro Osório*), 84.8% (*Santa Isabel do Sul*) and 81.2% (*Santa Vitória do Palmar*) of the simulated period, the calculation of performance metrics was done considering only the period of data without failures for each station.

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Table 2 - Fluviometric stations with level data used in the study.

Code	Name	Latitude	Longitude	Date	
				First	End
88575000	*Cerro Chato*	31°51'52.92"	53°16'5.88"	01/01/1980	31/12/2020
88750000	*Passo dos Carros*	31°42'50.04"	52°28'36.12"	01/01/1980	31/12/2020
88641000	*Pedro Osório*	31°51'47.88"	52°48'57.96'	01/04/2000	31/12/2020
88220000	*Picada da Areia*	32° 23' 8.00"	53°38'16.00"	01/01/1980	01/12/2000
88850000	*Cordeiro de Farias Bridge*	31°34'24.96"	52°27'45.00"	01/01/1980	31/12/2020
-	SGCDL-U*	31º48'46.80"	52º23'20.400"	01/01/1980	31/12/2020
-	SGCDL-D**	31º48'39.60"	52º23'16.800"	01/01/1980	31/12/2020
88900000	*Santa Isabel do Sul*	32° 9' 16.92"	52°37' 48.00"	01/01/1980	07/03/2016
88040000	*Santa Vitória do Palmar*	33°30'30.96"	53° 26' 9.96"	01/01/1980	14/05/2013

*SGCDL-U = São Gonçalo Channel Dam and its lock – Upstream; **SGCDL-D = São Gonçalo Channel Dam and its lock – Downstream.

Source: ANA e ALM (2022).

Data on water levels provided by monitoring agencies were treated to enable comparisons so that they could be in the same reference as the one of data generated by the model. Therefore, data on stations under investigation had their values adjusted by the difference between observed averages and simulation averages. Thus, both series were referred to Datum EGM-96, which was used by the DEM of the SRTM.

The MGB adapted by Possa et al. (2022) needs not only its traditional data but also insertion of the downstream condition, considering daily data on water levels observed in the São Gonçalo Channel Dam and its lock, as a downstream condition. After the calculation of declivity of values found in the Dam, 20 m was added to the observed values. The original DEM also had 20 m added to it to compensate for stream burning in the Mirim Lagoon. In addition, lateral connections were considered, since the MSGW lies on a plain, a fact that requires considering lateral discharge exchange among mini-basins in the Inertial MGB, the traditional method, based on the incorporation of connection channels among all adjacent mini-basins located in plain areas (Pontes et al., 2015). This study considered the parameter value of 100 m because it was introduced as the most suitable one to the study area in the model proposed by Possa et al. (2022).

Another aspect introduced by the model adapted by Possa et al. (2022) and included in this study was the insertion of sub-daily data on wind, a climate variable that shows alteration in the model. Sub-daily data on wind were incorporated into the modeling of the MSGW, since the area is greatly affected by the variable. Sub-daily data on wind collected by conventional stations located in the MSGW (Figure 3) were provided by the *Instituto Nacional de Meteorologia* (INMET) platform.

2.2.2. PROCESSING OF THE HYDROLOGICAL-HYDRODYNAMIC MODELING

Input data and pre-processing carried out by IPH-Hydro Tools enabled the following processes to be conducted in the MGB:

<u>Interpolation of data on rainfall</u>: Daily rainfall data enabled the MGB to carry out inverse distance squared weighted interpolation, based on coordinates of every rainfall stations up to coordinates of centroids of mini-basins (Alves et al., 2020). This process resulted in a file, which was needed to design the project used for simulating the model.

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Design of the file of observed discharge: designing a file with information on observed discharge that fits in the MGB was needed since it may be compared to information simulated by the model and used for its calibration, according to Alves et al. (2020). Therefore, data on discharge used by this study were organized in a file on every station and exactly the period of data used for rainfall interpolation. It should be highlighted that, in this process, location of fluviometric stations and their respective mini-basins had to be checked in the drainage system.

Estimate of evapotranspiration: the model estimated evapotranspiration by the Penman-Monteith method (Shuttleworth, 1993) with the use of data on air temperature, relative humidity of air, wind velocity, atmospheric pressure and insolation.

2.2.3 THE MGB ADAPTED BY POSSA ET AL. (2022)

The MGB adapted by Possa et al. (2022) considers not only information used by its traditional version but also downstream conditions, lateral connections, influence of wind velocity and direction and coefficient of friction. Thus, this study took into consideration:

Downstream condition: to make the model more robust, daily data on the water level on the São Gonçalo Channel Dam and its lock – Downstream were used and declivity was calculated in relation to values observed on the dam. Twenty m was added to those values and to the original DEM to compensate for stream burning in the Mirim Lagoon.

Lateral conditions: since the MSGW lies on a plain, the model must consider lateral discharge exchange among mini-basins in the Inertial MGB, the traditional method, based on incorporation of connection channels among all adjacent mini-basins that lie on plain areas (Pontes et al., 2015). Thus, the parameter value was 100 m, the most suitable one to the study area in the model proposed by Possa et al. (2022).

Sub-daily data on wind: one of the main changes proposed by Possa et al. (2022) was the incorporation of sub-daily data on wind into the modeling of the MSGW (Figure 4) since the region is strongly affected by the variable. This study uses this variable (wind), which was firstly introduced into the MGB with inertial propagation by Lopes (2017).

Coefficient of wind friction: this study used $2x10^{-6}$ as the coefficient of wind friction (Cd) because it was considered suitable by Possa et al. (2022). It exhibited the best performance metrics when it was simulated with sub-daily data on wind in the MSGW.

2.2.4. MODEL SIMULATION AND CALIBRATION

The model was simulated and calibrated with the use of inertial propagation from January 1st, 1980 to December 31st, 2020, i. e., 40 years. Calibration was carried out by comparing simulated and observed hydrograms. Performance metrics were the Nash-Sutcliffe coefficient (NS), Nash-Sutcliffe coefficient of flow logarithms (NSLog) and Relative Volume Error (Bias).

The NS coefficient is more sensitive to high discharge and ranges from infinite negative to 1, which is considered the perfect adjustment. Values above 0.75 are considered suitable while values between 0.36 and 0.74 are acceptable (Collischonn, 2001). The NSLog uses the same condition as the NS one. The closer to 1, the better the adjustment. The Bias exhibits the best adjustment

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regarding quantity of discharge generated by the MGB by comparison with discharge observed along time when approximated to 0 (Santos, 2022). This classification was used by Possa et al. (2022), Santos (2022), Brito Neto et al. (2021) and Oliveira (2014), as shown in Table 3.

Table 3 - Classification of performance indices.

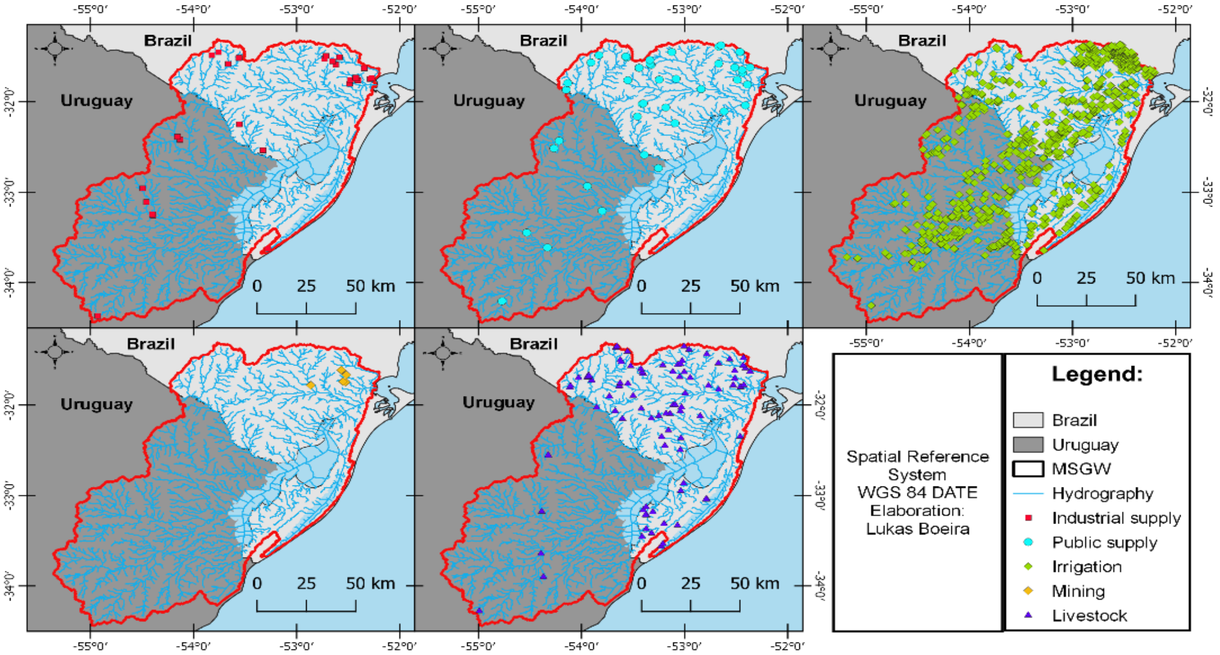
Classification	NS e NSLog	Bias (%)
Very good	0.75 < NS e NSLog ≤ 1.00	Bias (%) < ± 10
Good	0.65 < NS e NSLog ≤ 0.75	± 10 ≤ Bias (%) < ± 15
Satisfactory	0.50 < NS e NSLog ≤ 0.65	± 15 ≤ Bias (%) < ± 25
Unsatisfactory	NS e NSLog ≤ 0.50	Bias (%) ≥ ± 25

Source: Brito Neto et al. (2021) quoted by Oliveira (2014)

2.3. MULTIPLE USES

Data on water extraction in the Brazilian part of the basin were provided by the *Sistema de Outorgas de Água do Rio Grande do Sul* (SIOUT, 2021) while the ones in its Uruguayan part were supplied by the *Dirección Nacional de Aguas* (DINAGUA, 2019). Resulting data included water used for several purposes, such as industrial supply, public systems, irrigation, mining and livestock farming (Figure 4).

Figure 4 - Location of points granted for water use for industrial supply, public systems, irrigation, mining and livestock farming in the MSGW.



Granted discharge refers to demands in the region. The analysis must include water return after it is withdrawn, considering consumption patterns of every purpose. Relation between withdrawal and consumption is proportional to return coefficients of every type of use found in the literature. Thus, withdrawal discharge was multiplied by return coefficients shown in Table 4.

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Table 4 - Return coefficients of different purposes.

Purpose	Return coefficients
Public supply *	0.80
Industrial supply*	0.80
Irrigation **	0.20
Mining ***	0.75
Livestock farming *	0.20

Source: *Nota Técnica nº 56/2015/SPR_ANA (ANA, 2015); ** SRHU & FUNARBE. *Desenvolvimento de Matriz de Coeficientes Técnicos para Recursos Hídricos no* Brazil. Relatório Técnico, 2011 (Brasil, 2011); *** *Manual de Usos Consuntivos da Água no* Brazil: ANA (Brasil, 2019).

Return coefficients were calculated and uses of water were analized by considering withdrawn volumes and simulated ones (Q90). The former consist of the quantity of water that is withdrawn from the water resource to be used for a certain purpose. Data were provided by management agencies in Brazil and Uruguay. Simulated values consist of volumes of water calculated by the hydrological-hydrodynamic modeling of discharge Q90, which is the average volume available in every water resource 90% of the time.

Based on the previous data, two relevant indicators of scarcity which have been used by studies of management of water use were applied so as to diagnose scarcity levels in the MSGW, considering its annual water commitment (SEMA, 2020). Such indicators were detailed in items 2.3.1 and 2.3.2.

2.3.1 WATER COMMITMENT INDEX (WCI)

One of the main indices found in studies of water uses and withdrawal is the Water Commitment Index (WCI), which aims at defining socio-political limits and showing regions that require special attention regarding management of water demands. It is the relation between consumption (volume of water withdrawn for multiple uses) and reference discharge (SEMA, 2020) shown by Equation 1.

This study used reference discharge Q90, which defines grants of water uses in the MSGW in agreemen with Article 12 in the Plano Estadual de Recursos Hídricos do Rio Grande do Sul (PERH-RS, 2014). When the sum of withdrawal discharges exceeds 50% of respective reference discharges (Q90), it is considered special. Therefore, this study used reference discharges Q90 resulting from the modeling that encompassed 40 years and discharges found in every mini-basin corresponding to the outlet of adjacent sub-basins.

$$WCI = \frac{V}{VR} \times 100 \qquad \text{(Equation 1)}$$

where:

WCI is the Water Commitment Index, expressed as %;

V is the volume of water withdrawn for multiple uses, expressed as $m^3.s^{-1}$;

VR is the volume of reference Q90, expressed as $m^3.s^{-1}$.

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2.3.2 WATER EXPLOITATION INDEX (WEI)

Another significant index which has been used by studies of water balance as a management tool is the Water Exploitation Index (WEI). It has been widely used by the European Union as a tool to manage its waters considering the relation between total consumed discharge and average annual discharge (Equation 2). In this study, total consumed discharge was defined by data on users provided by regulatory agencies (SIOUT and DINAGUA) while average annual discharge was determined by the modeling carried out in every mini-basin where outlets of sub-basins under investigation are located. Such index enables to determine water scarcity by the classification shown in Table 5.

$$WEI = \frac{V}{VM} \times 100 \qquad \text{(Equation 2)}$$

where:

WEI is the Water Exploitation Index, expressed as %;

V is the volume of water withdrawn for multiple uses, expressed as $m^3.s^{-1}$;

VM is the average annual volume of the water resource, expressed as $m^3.s^{-1}$.

Table 5 - WEI classification.

Classification	Situation
0% a 5%	Excellent, where little or no management activity is required and therefore water is considered a free good;
5% a 10%	Comfortable, there may be a need for management to solve local problems of priority supplies;
10% a 20%	Worryingly, management activity is indispensable, requiring the realization of medium investments;
20% a 40%	Critical, requiring intense management activity and large investments;
>40%	Very critical.

Source: SEMA (2020)

3. RESULTS AND DISCUSSION

3.1 CHARACTERIZATION OF THE MSGW-IPH-HYDRO TOOLS AND HYDROLOGICAL MODELING - LARGE BASIN MODEL (MGB)

IPH-Hydro Tools led to the delimitation of the MSGW considering hydrological features of the model. A basin configuration whose total area is 58,613.01 km², with 15 sub-basins, was generated. Locations of fluviometric stations in the study area were used in the calibration process of the hydrological modeling. Figure 5A shows all 15 sub-basins; 4 are located in Brazil (4, 5, 6 and 7) while 8 are in Uruguay (8, 9, 10, 11, 12, 13, 14 and 15) and sub-basin 1 is in the interface Brazil-Uruguay. Besides, results of the discretization process of the basin, 1,777 mini-basins (Figure 5B) and HRUs

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were generated in the MSGW (Figure 5C), based on the map of Hydrological Response Units in South America (Fan et al., 2015). Areas and percentages of HRUs are shown in Table 6.

Figure 5 – Discretization of (A) sub-basins and (B) mini-basins used in the Mirim–São Gonçalo watershed and (C) the respective Hydrological Response Units (HRUs).

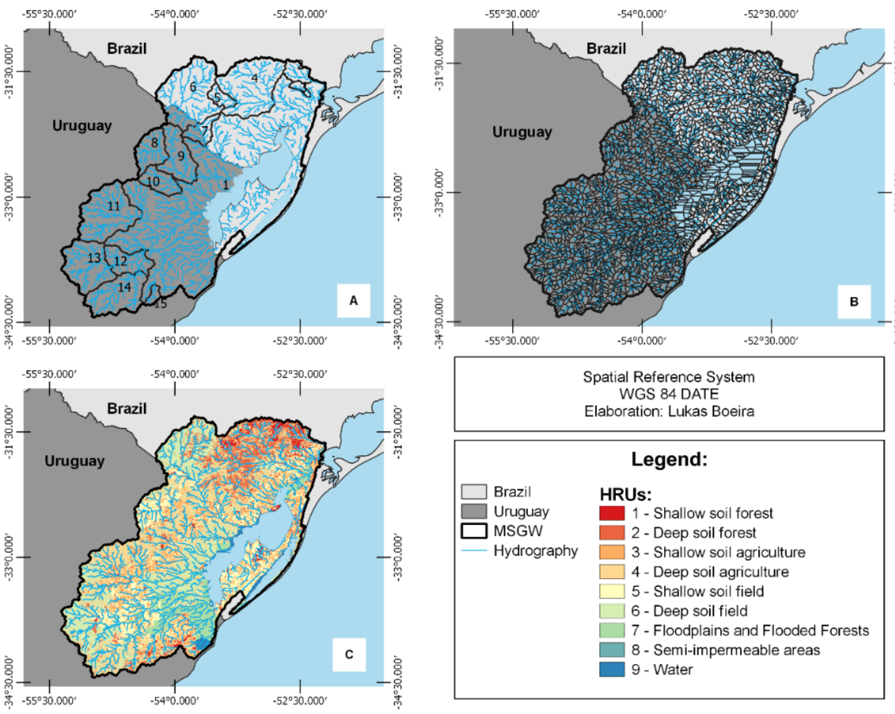

Table 6 - Percentages of every HRU in the MSGW.

HRUs	Area (km²)	Percentage (%)
Shallow soil forest	2148.28	3.67
Deep soil forest	4657.80	7.95
Shallow soil agriculture	9031.93	15.41
Deep soil agriculture	9841.41	16.79
Shallow soil field	10687.84	18.23
Deep soil field	12033.14	20.53
Floodplains and Flooded Forests	4361.81	7.44
Semi-impermeable areas	0.29	0.0005
Water	5850.51	9.98
Total	58613.01	100

Figure 5C and Table 6 show that the relevant feature in the MSGW is the deep soil field that stretches over 20.53% of the total area of the basin. It is followed by the shallow soil field (18.23%), deep soil agriculture (16.79%) and shallow soil agriculture (15.41%). Deep soil and shallow soil fields are expected in this region since both types of soil are favorable to certain economic activities, such as livestock farming, which predominate in the part of the MSGW that is located in Uruguay (Opplert et al., 2020). HRUs of agriculture in deep and shallow soil should also be highlighted since it is not expected in that region whose main economic activity is rice cultivation (Boeira et al., 2021; Oliveira et al., 2015). Santos (2022) analyzed the qualitative water balance in the sub-basin of the Jaquarão

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River (it corresponds to sub-basins 6, 7 and part of 1) and corroborated results of the HRUs in the region.

Pre-processing led to the hydrological-hydrodynamic modeling by the MGB adapted by Possa et al. (2022) from 1980 to 2020. Downstream conditions, lateral connections, sub-daily data on wind and coefficient of wind friction were inserted into the traditional MGB. Simulated daily discharges were compared to discharges observed in the fluviometric stations and evaluation of their results was based on the following performance metrics: NS, NSLog and Relative Volume Error (Bias). Results are shown in Table 7.

Table 7 - Fluviometric stations and their performance metrics.

Code	Name	River	NS	NSlog	Bias (%)
88850000	*Cordeiro de Farias Bridge*	Pelotas Stream	0.531	0.527	14.374
88750000	*Passo dos Carros*	Fragata Stream	0.506	0.528	1.936
88575000	*Cerro Chato*	Basílio Stream	0.513	0.346	-34.519
88641000	*Pedro Osório*	Piratini River	0.519	0.673	-3.411
00000100	*Paso Centurión*	Jaguarão River	0.257	0.616	-18.695
88220000	*Picada da Areia*	Jaguarão River	0.423	0.583	-28.742
00000096	*Paso Borches*	Tacuarí River	0.373	0.405	-8.837
00000097	*Paso Dragón*	Tacuarí River	0.391	0.181	-8.321
00000109	*Vergara*	Parao Stream	0.059	0.616	-37.903
00000010	*Puenta Ruta 8 (Vieja)*	Olimar Grande River	0.167	0.362	-21.831
00000014	*Picada de Corbo*	Cebollatí River	0.096	0.296	-7.574
00000128	*Paso del Avestruz*	Del Aiguá Stream	0.050	0.015	-34.950
00000015	*Paso Averías*	Cebollatí River	0.111	0.298	-14.706
00000111	*India Muerta*	India Muerta Stream	0.127	0.221	-51.917

NS: Nash-Sutcliffe coefficient; NSLog: Nash-Sutcliffe coefficient of flow logarithms; Bias: Relative Volume Error (%). Statistics based on absolute values.

Table 7 shows that values of performance metrics in the MSGW were in the classification ranges introduced by Brito Neto et al. (2021) and Oliveira (2014), in which three stations – *Cordeiro de Farias* Bridge (sub-basin 2), *Passo dos Carros* (sub-basin 3) and *Cerro Chato* (sub-basin 4) – exhibited unsatisfactory values of NS. However, the best results of NSLog in the modeling took place in the *Pedro Osório* station (sub-basin 5), classified into Good, followed by *Cordeiro de Farias* Bridge, *Passo dos Carros, Paso Centurión* (sub-basin 6), *Picada da Areia* (sub-basin 7) and *Vergara* (sub-basin 10), whose NSLog was satisfactory. Concerning Bias, *Passo dos Carros, Pedro Osório, Paso Borches* (sub-basin 8), *Paso Dragón* (sub-basin 9) and *Picada de Corbo* (sub-basin 12) were the stations that reached the best classification (Very Good). Possa et al. (2022) carried out modeling from 1980 to 2010 in the MSGW while Santos (2022) did it in the Jaguarão River (sub-basins 6 and 7 in this study from 1980 to 2010) and Lopes (2017) did it in the Patos Lagoon - Mirim Lagoon Complex (which encompassed the MSGW) from 1970 to 2010 and reached similar metrics. Possa et al. (2022) found NS values in the same classification in almost all Brazilian part of the MSGW, except *Cerro Chato* station, whose NS and NSLog were low in the *Cordeiro de Farias* Bridge station.

Santos (2022) reached satisfactory NS in both stations, satisfactory NSLog in *Picada da Areia* station, Good NSLog in *Paso Centurión*, unsatisfactory Bias in *Picada da Areia* and satisfactory Bias in *Paso Centurión* in a study that modeled the period from 1980 to 2010. Most values reached by Lopes (2017) in his modeling were classified into unsatisfactory NS and NSLog in stations in Uruguay and

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into Good in Brazil. In the Uruguayan part of the basin, the model was quite difficult, i. e., there was low adjustment in some places between observed and simulated data. It may have occurred because data were not provided by rainfall stations in the Uruguayan part of the basin in the period under study, a fact that was highlighted by Possa et al. (2022) and Lopes (2017).

Average NS values in the whole basin (Table 7) show that the modeling exhibited performance 0.29 (unsatisfactory) in the representation of peak discharges. When only sub-basins of the Brazilian part of the MSGW, performance was 0.50 (satisfactory) and 0.18 (unsatisfactory) in the Uruguayan part. Resulting average NSLog values, which mean adjustment to minimum discharges, show that, in the Brazilian part, the model had performance 0.53 (satisfactory) while, in the Uruguayan part, it was 0.33 (unsatisfactory). Finally, most percentage errors of average volumes exhibited negative values; these shows that the model underestimates observed discharge. Munar et al. (2018), who conducted an 11-year hydrological-hydrodynamic modeling in the Mirim Lagoon (2000-2010), found that representations of models in Brazilian and Uruguayan parts were similar. The authors inferred that the fact that precision of modeling in the Uruguayan part was not so good as the one in the Brazilian part may be attributed to the small number of pluviometers in Uruguay. Hence, the need to carry out interpolation of data on distant spots located in the Brazilian part.

In the station located in the *Pelotas* Stream, peak discharge generated by the model was 465.83 $m^3.s^{-1}$, while maximum observed peak discharge in this station was 1074.51 $m^3.s^{-1}$ in an only case in 2017. In the other years under analysis, it did not exceed 489.45 $m^3.s^{-1}$. In the *Piratini* River station, peak discharge generated by the model was 1886.24 $m^3.s^{-1}$ while observed data on discharge did not exceed 4383.06 $m^3.s^{-1}$. In the *Jaguarão* River station, simulated peak discharge was 1025.31 $m^3.s^{-1}$ and the highest observed discharge was 974.00 $m^3.s^{-1}$. Regarding modeling in the Uruguayan part, the station located in the Tacuarí River exhibited maximum simulated discharge of 979.63 $m^3.s^{-1}$ while the observed value was 1751.42 $m^3.s^{-1}$. The *Parao* Stream station showed simulated peak discharge of 384.41 $m^3.s^{-1}$ and observed one of 11830.83 $m^3.s^{-1}$ in an only case; the other peaks oscilated around 3000 $m^3.s^{-1}$. Finally, the *Cebollatí* River exhibited peak discharges of 682.82 $m^3.s^{-1}$ and observed ones were around 4440 $m^3.s^{-1}$.

Lopes (2017), Munar et al. (2018) and Possa et al. (2022) faced the same situation and reported the difficulty that the model had in representing the basin in the Uruguayan part. Concerning minimum discharges, the model exhibited similar maximum discharges; thus, it was satisfactory in the Brazilian part and unsatisfactory in the Uruguayan one.

In the analysis of levels in the MSGW, the strategy used for making observed data keep in the same reference as data generated by the model (Datum Vertical EGM96) was important and necessary. Table 8 shows averages of observed and simulated levels and the difference between them. It is the difference between zero in measuring rulers and the sea level. Average simulated levels ranged between 2.25 m in the port in *Santa Vitória do Palmar* and 0.763 in the *Cerro Chato* station.

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Table 8 - Averages of observed and simulated levels and their differences.

Name	Average level observed (m)	Simulated average level (m)	Difference (m)
Cerro Chato	0.763	0.369	0.394
Passo dos Carros	1.344	0.405	0.940
Pedro Osório	2.814	2.423	0.391
Picada da Areia	1.814	0.634	1.180
Cordeiro de Farias Bridge	0.915	0.265	0.650
SGCDL-U*	1.052	0.956	0.096
SGCDL-D**	0.936	0.956	-0.019
Santa Isabel do Sul	1.740	1.645	0.095
Santa Vitória do Palmar	1.914	2.250	-0.336

*SGCDL-U = São Gonçalo Channel Dam and its lock – Upstream; **SGCDL-D = São Gonçalo Channel Dam and its lock – Downstream.

The model simulated levels in spots under observation adequately, mainly on the São Gonçalo Channel Dam and its lock, both upstream and downstream. NS performance metrics were above 0.91 and classified into Very Good; RMSE was below 0.13 and R was close to 1, showing strong correlation. Afterwards, both *Santa Isabel do Sul* and *Pedro Osório* stations exhibited "Good" NS. Low values of RMSE showed good precision of estimates by comparison with observed data and R above 0.8, very close to strong correlation. Considering stations under analysis, the one that did not stand out was *Picada da Areia*, in the boundary between Brazil and Uruguay. NS performance metrics were 0,364 (unsatisfactory), RMSE was close to 0.9 and R was close to 0.7. Such results may result from lack of data on rainfall to carry out the model in the area close to the station (Uruguay).

Some authors, such as Munar et al. (2018), reached results of water levels in the Mirim Lagoon based on the MGB which were well represented. The *Santa Isabel do Sul* station exhibited NS performance metrics of 0.91, RMSE = 0.321 m and Bias = - 0.32 m. The authors point out that, because the Mirim Lagoon has a large surface area and low depth (4.5 m, on average), winds strongly affect dynamic behavior of water levels, a fact that also occurs in water resources nearby, such as the Patos Lagoon, as shown by Fernandes et al. (2002, 2005), and the Mangueira Lagoon (Fragoso et al., 2011). According to Munar et al. (2018), such influence is due to stress produced by the wind; southern winds push water northwards and increase water levels in the *Santa Isabel do Sul* station whereas northern winds increase water levels southwards.

Besides the influence of winds on water levels, another relevant factor in the analysis of oscillations in levels in the Mirim Lagoon is its multiple uses, mainly irrigation. Such use was analyzed by Munar et al. (2018), whose results showed that the main hydrodynamic processes in the Mirim Lagoon are controlled in the seasonal scale (months) by river discharges of its main affluents and water withdrawal for multiple uses (irrigation) in a lower scale (days) by winds. In their 11-year study of the Mirim Lagoon, the authors also highlighted that simulated water levels showed that water withdrawal for irrigation affected water levels in the lagoon significantly.

3.2 MULTIPLE WATER USES

A study of water withdrawal from water resources that compose the MSGW identified 1,099 activities registered by regulatory agencies in Brazil and in Uruguay. Irrigation prevails since there are 919 records (86.62% of all uses in the basin). Livestock farming, public supply, industrial supply and mining follow with 92, 45, 38 and 5 records, respectively (Table 9).

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Table 9 - List of grants by type of use in the MSGW.

Sub-Basins	Water uses IS.	PS.	Liv.	Min.	Irri.	Total	%
1	17	16	40	2	565	640	58.23
2	3	3	5	1	144	156	14.19
3	5	1	2	1	3	12	1.09
4	2	13	14	1	92	122	11.10
5	0	1	1	0	3	5	0.45
6	6	7	24	0	56	93	8.46
7	1	0	1	0	3	5	0.45
8	3	2	2	0	15	22	2.00
9	0	0	0	0	11	11	1.00
10	0	1	0	0	5	6	0.55
11	0	0	0	0	4	4	0.36
12	0	0	2	0	12	14	1.27
13	0	0	0	0	5	5	0.45
14	1	1	1	0	1	4	0.36
15	0	0	0	0	0	0	0.00
Total	38	45	92	5	919	1099	100,0
%	3,46	4,09	8,37	0,45	86,62	100,00	

IS. = Industrial supply; PS. = Public supply; Liv. = Livestock farming; Min. = Mining Irri. = Irrigation.

Table 9 also shows that regulated uses predominate in sub-basin 1, where the Mirim Lagoon is located; it represents 58.23% of grants (640 uses) in the MSGW. Sub-basins 2 and 4 follow with 14.19% (156 uses) and 11.10% (122 uses), respectively. It should be highlighted that, considering all regulated uses, most are found in the Brazilian part of the basin, i. e., 71.16% (782 uses). Percentages of average withdrawn discharge, which are shown in Table 10, were based on data on volumes of withdrawn water and return coefficients of every multiple use in the basin.

Table 10 - Water withdrawal (total flow and %) for multiple uses in the MSGW. Data issued by regulatory agencies in Brazil and Uruguay.

Water use	Total Flow ($m^3.s^{-1}$)	MSGW (%)
Industrial supply	11.66	0.564
Public supply	80.96	3.916
Livestock farming	610.24	29.513
Mining	0.07	0.004
Irrigation	1364.79	66.004
Total	2067.74	100.000

Table 10 highlights the use of irrigation: 1364.79 $m^3.s^{-1}$, which corresponds to 66% of water withdrawn from the MSGW per year. MVOTMA (2017) pointed out the importance of irrigation as the main water use in the Uruguayan part of the MSCW; it represents 98.5% of all water withdrawal, followed by public supply (1.1%) and industrial supply (0.2%).

Flooded rice cultivation is the main economic activity in the region and the main factor of withdrawal of large volumes of water between December and March. According to Munar et al. (2018), water withdrawal from the Mirim Lagoon for irrigation strongly affects levels of water resources. Their study mentions the use of hypothetical values of pumping rates; the extreme scenario is 3 $L.s^{-1}$, which generates monthly oscillation between 0.20 and 0.25 in the Mirim Lagoon.

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Table 10 also shows that livestock farming accounts for 29.5% of water withdrawn from the basin since it plays an important socio-economic role in the region.

Data on water withdrawal led to the analysis that included both scarcity indices WCI and WEI, which are important management instruments of water use in hydrographic basins.

3.2.1 WATER COMMITMENT INDEX (WCI)

Calculation of the WCI in the MSGW was based on Q90 resulting from modeling of every sub-basin (15) and their respective average discharges granted for multiple uses of water (Table 11).

Table 11 - Water Commitment Index (WCI) for each MSGW sub-basin outlet.

Sub-Basins	Average consumption ($m^3.s^{-1}$)	Q90 ($m^3.s^{-1}$)*	WCI (%)
1	142.800	342.524	41.690
2	2.642	2.634	100.296
3	0.127	0.689	18.386
4	10.059	4.629	217.305
5	0.605	23.191	2.608
6	13.718	8.171	167.885
7	1.158	11.733	9.866
8	0.535	2.649	20.186
9	0.203	16.192	1.255
10	0.181	1.883	9.590
11	0.002	20.206	0.012
12	0.400	9.637	4.148
13	0.006	14.529	0.042
14	0.010	30.390	0.033
15	0.000	1.195	0.000

*Q90 discharges, expressed as $m^3.s^{-1}$, were generated by hydrological-hydrodynamic modeling of mini-basins that are in the outlets of their sub-basins.

Q90 discharges generated by the modeling range from 0.689 $m^3.s^{-1}$ to 342.524 $m^3.s^{-1}$, mainly in sub-basins where the Mirim Lagoon (sub-basin 1), *Del Aiguá* Stream (sub-basin 14), *Basílio* Stream (sub-basin 5), *Olimar Grande* River (sub-basin 11), *Tacuarí* River (sub-basin 9), *Cebollatí* River (sub-basin 13) and *Jaguarão* River (sub-basin 7) are located.

Table 11 shows that average water consumption in sub-basin 1 is 142.8 $m^3.s^{-1}$, followed by sub-basins 6 and 4, whose values were 13.718 $m^3.s^{-1}$ and 10.059 $m^3.s^{-1}$, respectively. In most MSGW, WCIs are below 50% of Q90, which means that the sum of discharges withdrawn by the sub-basin does not exceed 50% of the reference discharge, which is Q90, in this case. The PERH/RS (2014) considers that the discharge is special when the WCI is above 50%. In the MSGW, three sub-basins were considered special: sub-basin 2 (100.296%), sub-basin 4 (217.305%) and sub-basin 6 (167.885%). WCIs are shown in Figure 6.

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Figure 6 – WCI classification of sub outlet used in the MSGW modeling.

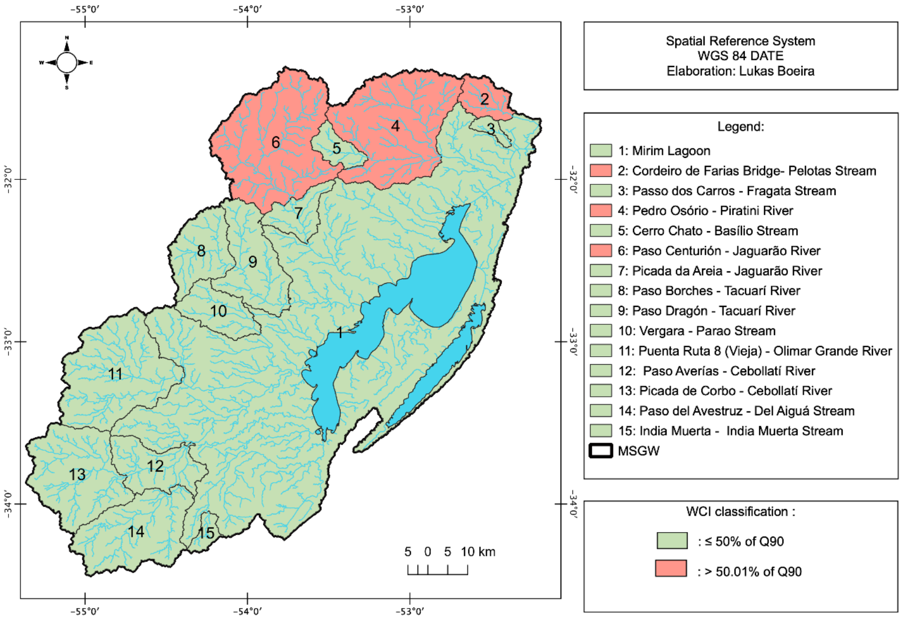

Figure 6 shows that most WCIs in the MSGW are below the limit, i. e., 50%, in green, but the three sub-basins in a special situation exhibit WCIs above 50% of Q90 and are located in the Brazilian part of the basin. They require attention because their demands regarding multiple uses are above Q90.

Studies of hydrographic basins that exhibit indexes, such as WCI, are very important to the management of water resources, mainly to help managers decide which and when thay should issue warnings about water withdrawal and indices used by agencies, such as the *Secretaria de Meio Ambiente e Infraestrutura do Rio Grande do Sul* (SEMA), to develop Plans for Hydrographic Basins. A reference is the Plan for the *Mampituba* River Basin, whose WCIs were below 50%.

Similar situations to the ones found in sub-basins 2, 4 and 6 were observed in the hydrographic basin of the *Contas* River (BHRC), in Bahia (BA), Brazil, and described by the *Instituto do Meio Ambiente e Recursos Hídricos* (INEMA). Its WCI was in a critical situation (INEMA, 2019).

It should also be emphasized that basins with higher WCIs – sub-basins 4 and 6 – regarding granted volumes exhibit representative discharges in the use of livestock farming, 91.07% and 78.95%, respectively, of the total withdrawn discharge. It corroborates the study published by the SEPLAG/DEPLAN (2020), which reports that the number of cattle heads in RS, in the MSGW, is 100,000-200,000 per year, on average. However, the average in the state from 2016 to 2018 was 13,164,945 cattle heads per year.

Santos (2022) carried out the quantitative balance of superficial waters in a sub-basin in the MSGW, mainly in the *Jaquarão* River, which comprises the area of sub-basins 6, 7 and part of sub-basin 1 under investigation by this study. The analysis of the Water Stress Index (WSI) was based on Q90 to observe whether the area is subject to water stress in summer (from December to March) caused by water withdrawal aiming at flooded rice cultivation.

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The key water resource in the MSGW, the Mirim Lagoon (sub-basin 1), exhibited WCI of 41.690% while water consumption for multiple uses was 142.8 $m^3.s^{-1}$. It is a warning, since the Mirim Lagoon is close to the critical situation, considering that further consumption of about 27 $m^3.s^{-1}$ exceeds 50% of Q90. Thus, it is clear that there should be rigorous criteria to new grants for water withdrawal from the Mirim Lagoon to avoid the critical scenario in future water use.

3.2.2 WATER EXPLOITATION INDEX (WEI)

The WEI was reached by discharges modeled by the 40-year study, considering average discharges ($m^3.s^{-1}$) in the MSGW (Table 12).

Table 12 - Water Exploitation Index (WEI) of every outlet in the MSGW.

Sub-Basins	Average consumption ($m^3.s^{-1}$)	Qmean ($m^3.s^{-1}$)*	WEI (%)
1	142.7997	742.421	19.234
2	2.6418	11.318	23.342
3	0.1267	3.225	3.928
4	10.0585	14.710	68.379
5	0.6049	90.939	0.665
6	13.7177	54.534	25.154
7	1.1576	73.801	1.568
8	0.5348	23.218	2.303
9	0.2032	56.113	0.362
10	0.1806	16.323	1.106
11	0.0024	73.687	0.003
12	0.3997	50.669	0.789
13	0.0061	52.404	0.012
14	0.0101	101.370	0.010
15	0.0000	6.572	0.000

* Qmean, expressed as $m^3.s^{-1}$, generated by the hydrological-hydrodynamic modeling of mini-basins where outlets of their respective sub-basin are located.

The WEI highlights that a large part of the MSGW fits into the best situation (from 0% to 5%), which is considered excellent. It may be inferred from few management activities – or none – since water that is available in the area may be treated either as a resource with unlimited uses or as a free asset. Eleven out of 15 sub-basins under study exhibited WEIs in this range.

In sub-basin 1, whose main reference is the Mirim Lagoon, the WEI was considered alarming and good management of water resources is fundamental. Besides, it should be pointed out that the sub-basin was almost considered in a critical situation (from 20% to 40%), the cases of sub-basins 2 and 6, which need deep management and large investments. The analysis of results of WCIs in sub-basin 1 shows that the Mirim Lagoon is close to the withdrawal limit. If there is further water withdrawal, attention should be paid to the influence it exerts, mainly in terms of water levels for multiple uses. Finally, sub-basin 4 in the MSGW was found to be in a very critical situation since it has the worst WEI, i. e., above 40%.

SPGG/DEPLAN (2021) issued the following data on rice production in the sub-basin 1 (the Mirim Lagoon) in RS: its main producer is *Santa Vitória do Palmar*, whose production ranges from 400,000.01 to 671,790.33 t/year, followed by *Arroio Grande* (200,000.01 – 400,000.00 t/year), *Capão do Leão, Jaguarão, Pelotas* and *Rio Grande* (50,000.01 – 200,000.00 t/year). All regions are in sub-basin 1 or withdraw water from the Mirim Lagoon, which is located in the same area. In

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addition, the study shows that RS produces 7,753.663 t/year of paddy rice, on average; it means that the region where the MSGW produces more than the average produced by the state. Figure 7 shows all results and their spatial distribution.

Figure 7 - WEI classification for sub-basins in the MSGW.

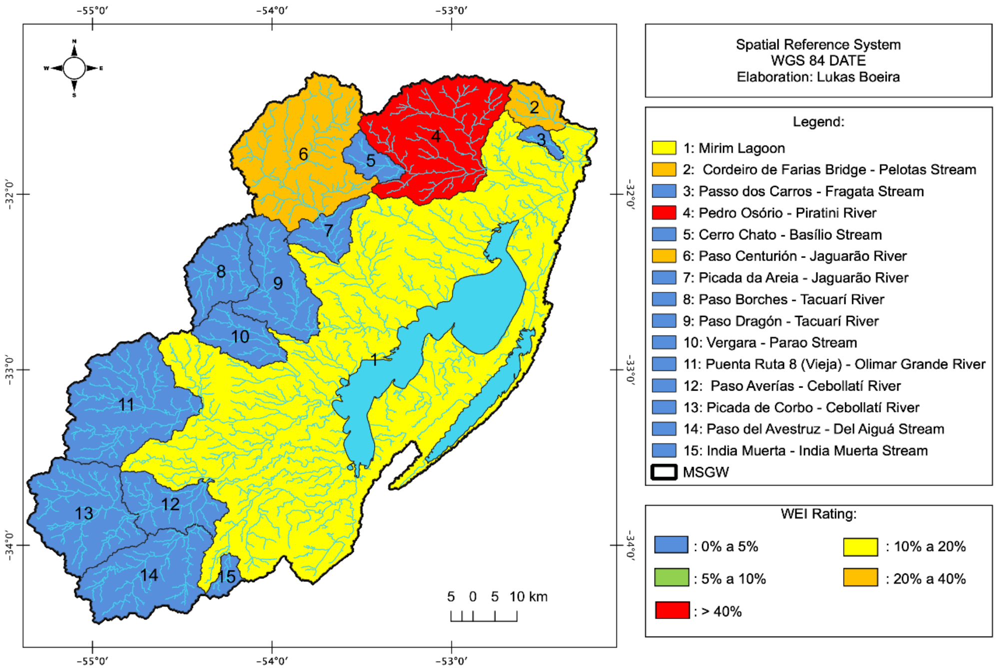

Figure 7 shows that most of the Uruguayan part of the basin is in excellent situation but water withdrawal is alarming; consequently, water availability in the Brazilian part of the MSGW is worrisome. The sub-basins whose situation is alarming and critical are the ones where livestock farming and irrigation are the main activities. The worster situation is found in sub-basin 4, where livestock farming withdraws 109.93 $m^3.s^{-1}$ annually. It is a high volume by comparison with its other uses, which require just 10.78 $m^3.s^{-1}$. One of the problems related to grants in general is the large volume of water used for livestock farming, by comparison with the other activities.

Some studies, such as the Plan for the *Mampituba* River Basin, which use both WEI and WCI – significant tools of management of water resources – reported predominance of the WEI below 5% (excellent), a situation that is similar to the one found in the MSGW. In the *Mampituba* River Basin, situations were excellent and comfortable (from 5% to 10%); thus, this basin does not need special attention related to its current water uses (SEMA, 2020).

When the WEI was applied to the area of the *Jaguarão* River, between Uruguay and Brazil (Santos, 2022), the index was excellent (from 0% to 5%) in 9 out of 12 sub-basins. Exceptions were 3 sub-basins located in the Brazilian part of the MSGW; in this study, it is part of sub-basins 1, 6 and 7, which ranged from comfortable (sub-basin 6) to alarming (sub-basin 7) and critical (sub-basin 1), very close to sub-basin 4, where the worst WEI was found. It requires intense management to mitigate problems in sub-basins 7 and 1. It may be inferred that, in the area of the *Jaguarão* River, in both Brazil and Uruguay, problems related to water use refer to the offer of water resources for different uses, mainly in the Brazilian part of the basin, a fact that corroborates results of this study.

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Visentin and Guilhoto (2019) evaluated the main water users in Brazil in terms of the Blue Virtual Water Content and impacts of water withdrawal by applying the WEI to hydrographic basins in the national plan for water resources. The authors reported that, in the RS Seashore basin, in the Brazilian part of the MSGW, the WEI was very critical (WEI > 40%) in the analysis of uses in 2009.

4. CONCLUSION

This study is showing the importance of hydrological-hydrodynamic modeling to the MSGW, a hydrographic basin that has relevant environmental and economic roles, mainly related to agriculture and livestock farming. The following issues should be emphasized:

I. With the analysis of indices related to the multiple uses of water abstraction from the MSGW springs, used in the modeling, it was possible to verify the capacities of Mirim Lagoon and the main tributaries of the basin in terms of water supply, where the Brazilian portion of the basin presents a situation that demands greater care and attentive management of the volumes of water collected;

II. From the simulated levels, a low occurrence of the average value, less than 0.50 meters, can be seen between the water levels of the model stations (Santa Isabel do Sul and Santa Vitória do Palmar), according to ANA Resolution No. 170/2013, therefore, it is recommended to keep this value as a limiting factor.

III. With regard to the limitations and uncertainties of the study, the low availability of data for the Uruguayan portion of the MSGW stands out, resulting in low model performance metrics. In turn, with regard to multiple uses, all water grants effectively released by the licensing bodies of the two countries (Brazil and Uruguay) were considered, being a pioneering study in this survey. However, it is known that, due to lack of inspection, there is illegal water abstraction in certain places for the most diverse multiple uses, which may increase the abstraction load from the springs.

IV. Therefore, such a study is of great importance to give a basic idea to municipal and regional managers regarding water limitations along the MSGW.

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