Evaluation of the new maximum water authorized in Rio de Janeiro state

Avaliação da nova vazão máxima outorgável do estado do Rio de Janeiro

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RESUMO
A outorga é um instrumento relevante da Política Nacional de Recursos Hídricos e visa garantir o controle quantitativo e qualitativo dos cursos d´água, assegurando a manutenção dos usos múltiplos e o direito de acesso à água. A maioria dos órgãos gestores de recursos hídricos brasileiros adota, na avaliação da disponibilidade hídrica, as vazões máximas outorgáveis representadas por porcentagens das vazões de referência $Q_{7,10}$ e $Q_{95\%}$. O Instituto Estadual do Ambiente, órgão gestor dos recursos hídricos do estado do Rio de Janeiro, calculava a disponibilidade hídrica com base na vazão máxima outorgável de 50% da $Q_{7,10}$, e a partir de 2019, passou a adotar 40% da $Q_{95\%}$. Tendo em vista a diferença entre os valores, buscou-se avaliar a magnitude e o impacto da atual vazão máxima outorgável nos processos de outorga pelo uso da água no estado do Rio de Janeiro, inserido em quase sua totalidade na sub-bacia 59. A partir dos resultados alcançados, recomenda-se a adoção de critério mais conservador representado pela vazão de 30% da $Q_{95\%}$, estimada em nível mensal.

Palavras-chave: gestão de recursos hídricos, outorga, INEA, sub-bacia 59.

ABSTRACT
A water rights permit is an important instrument of the Brazilian National Water Resources Policy and aims to ensure the quantitative and qualitative control of watercourses, guaranteeing the maintenance of multiple uses and the right of access to water. Most Brazilian water resource management agencies adopt, in the evaluation of

water availability, the maximum water authorized, represented by percentages of the $Q_{7,10}$ and $Q_{95\%}$ reference flows. The State Institute of the Environment, the governing body of the water resources in the state of Rio de Janeiro, calculated water availability based on the maximum water authorized of 50% of $Q_{7,10}$, and since 2019, 40% of $Q_{95\%}$ has been adopted. Considering the difference between the values, we evaluated the magnitude and impact of the current maximum water authorized in granting processes for water use in Rio de Janeiro state, which is inserted almost entirely in subbasin 59. Based on the results, it is recommended to adopt a more conservative criterion represented by 30% of $Q_{95\%}$, estimated at the monthly level.

Keywords: water resource management, water rights permit, INEA, subbasin 59.

1 INTRODUCTION

The intense use of water resources has resulted not only in problems related to lack of water availability but also in the degradation of water quality as a consequence of domestic and industrial effluent discharge, often with little or no treatment (Hipólito & Vaz, 2013).

In Brazil, Law No. 9,433, of January 8, 1997, established the National Water Resources Policy (PNRH, for its acronym in Portuguese). One of the main instruments of this policy is the granting of water use rights, which seeks to ensure the quantitative and qualitative control of water uses and the effective exercise of water access rights, according to art. 11 (Brasil, 1997).

The amount of water to be granted is defined based on the criteria adopted by the management agencies, always taking into account the domain of the water bodies (Gomes *et al.*, 2004). The granting process is directly related to the knowledge of water availability, determined from the estimation of reference flows, which constitute the upper limit of water use in a water body (Ribeiro, 2000).

Resolution 357/2005 of the National Environmental Council (CONAMA, for its acronym in Portuguese), in its art. 2, defines the reference flow as *the water body flow used as the basis for management, considering the multiple water uses and the necessary articulation of the bodies of the National Environment System (SISNAMA) and the National Water Resources Management System (SINGRH)* (Brazil, 2005).

According to Hora (2012), since the unlimited use of water can generate water scarcity or conflicts between users, most public agencies that manage water resources have adopted, as a conservative criterion, restricting the granting of water rights to percentages of reference flows.

The National Water and Sanitation Agency (ANA, 2011) reports that the reference flows most used by management agencies are $Q_{7,10}$ and $Q_{95\%}$. The first represents the lowest mean streamflow over seven consecutive days that would occur with a return period of 10 years. The second is determined from gaging station observations, where in 95% of the observation period, the streamflow were equal to or greater than it. The calculation of $Q_{7,10}$ is probabilistic, while that of $Q_{95\%}$ results from a frequency analysis.

According to Tucci (2002), $Q_{7,10}$ represents a minimum state condition. It reflects a critical situation of scarcity (Oliveira & Fioreze, 2011). On the other hand, $Q_{95\%}$ characterizes a condition of permanence of a recessive flow state, reflecting the behavior of a basin in dry periods (Reis *et al*., 2008).

The state of Rio de Janeiro, until 2019, adopted $Q_{7,10}$ as the reference flow, and 50% of $Q_{7,10}$ in the calculation of water availability, called the maximum water authorized (MWA) (SERLA, 2007). From then on, the reference flow changed to $Q_{95\%}$ and the MWA to 40% of $Q_{95\%}$ (INEA, 2019).

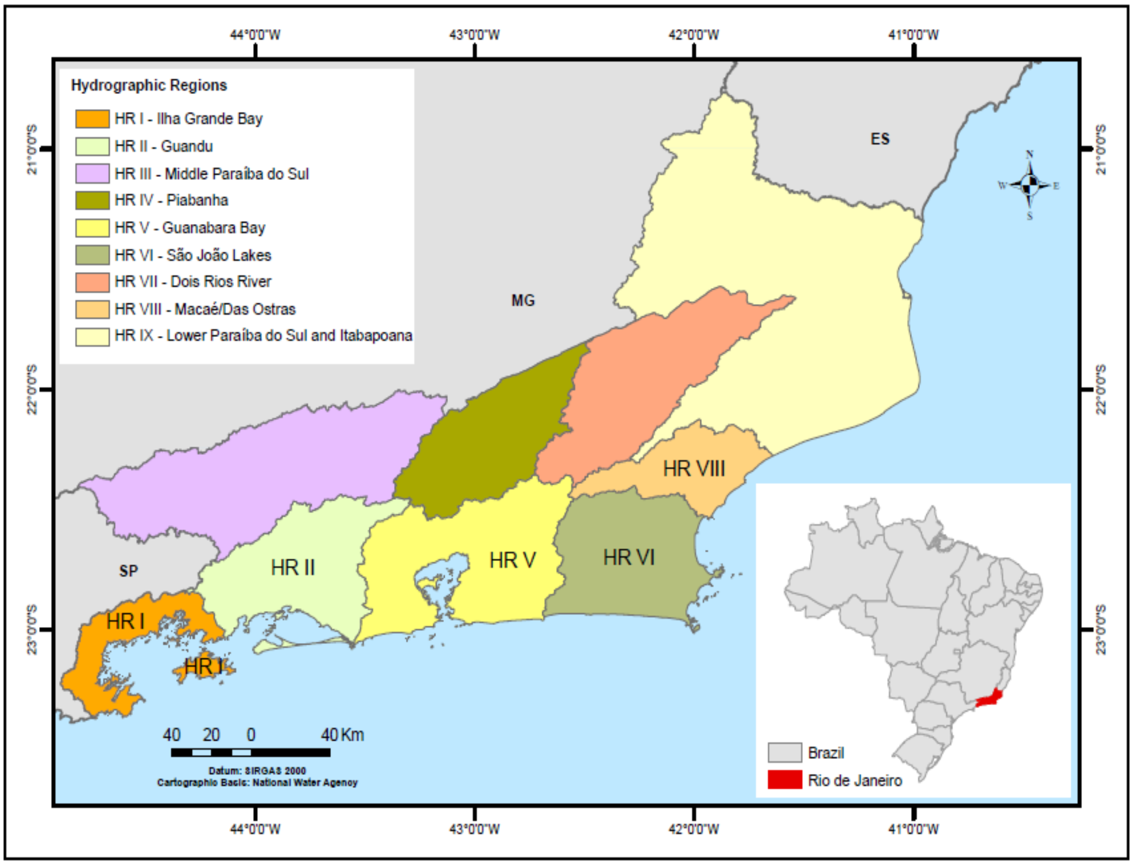
Based on the above, a study was conducted comparing the $Q_{7,10}$ and $Q_{95\%}$ reference flows and on the impact of the current MWA defined by the State Environmental Institute (INEA), for its acronym in Portuguese) on water availability to be considered in the granting of water use rights. For this purpose, subbasin 59 was selected because it encompasses, the state of Rio de Janeiro in almost all its entirety, with most of its rivers being under the state's domain and because it is a region lacking hydrological information (COPPETEC, 2014).

2 MATERIALS AND METHODS

Subbasin 59 incorporates the hydrographic region of the Southeast Atlantic, formed by the watersheds of the rivers that flow into the Atlantic Ocean, in the southeastern section of the country (Brazil, 2003). It has a drainage area that extends between the mouth of the Paraíba do Sul River and the border between the states of Rio de Janeiro and São Paulo.

However, the State Council for Water Resources (CERHI, for its acronym in Portuguese), through resolution no. 107 of May 22, 2013, established the division of the state into 9 hydrographic regions, as illustrated in Figure 1 (CERHI-RJ, 2013).

Figure 1. Hydrographic regions of the state of Rio de Janeiro. Source: Adapted from COPPETEC (2014).



Based on Figure 1, it is observed that region IX, called Lower Paraíba do Sul and Itabapoana, encompasses the channel and lake systems of the municipality of Campos, as well as the Pomba, Muriaé, Paraíba do Sul and Itabapoana rivers, all under federal domain, which are managed by ANA. Therefore, in the present study, we chose to consider hydrographic regions I (Ilha Grande Bay); II (Guandu); V (Guanabara Bay), VI (São João Lakes) and VIII (Macaé and das Ostras).

To conduct the study, the existing gaging stations in the study region were consulted based on the inventory available on ANA's HidroWeb Portal. The HidroWeb Portal is a tool that is part of the National Water Resources Information System (SNIRH, for its acronym in Portuguese) and that provides access to the database that contains all the data collected by the National Hydrometeorological Network (RHN, for its acronym in Portuguese), gathering data on river levels, flow rates, rainfall, weather, water quality and sediments (ANA, 2020).

The gaging network of subbasin 59 comprises a total of 388 stations. As an initial criterion, we sought those that presented a historical series of streamflows consisting of at least 5 years of complete data, as recommended by the Brazilian Geological Service

(CPRM, 2002). Based on this criterion and on the data available on HidroWeb, 12 gaging stations were selected, of which 7 are in operation and 5 are deactivated (Table 1).

Table 1. Gaging stations located in subbasin 59 and inside Rio de Janeiro state.

Code	Name	Latitude	Longitude	Area (km²)	River
59100000	Macabuzinho	-22:05:09	-041:44:22	630	Macabu
59120000	Macaé de Cima	-22:22:20	-042:27:44	67	Macaé de Cima
59125000	Galdinópolis	-22:22:08	-042:22:45	104	Macaé
59135000	Piller	-22:24:33	-042:20:10	71	Bonito
59180000	Correntezas - Old	-22:32:21	-042:24:24	322.8	São João
59181000	Correntezas - New	-22:32:35	-042:23:45	404	São João
59235000	Cachoeiras de Macacu	-22:29:00	-042:40:00	151	Macacu
59240000	Parque Ribeira	-22:35:23	-042:44:06	289	Macacu
59245000	Quizanga	-22:34:00	-042:51:00	353	Guapiaçu
59245100	Orindi	-22:33:00	-042:54:00	47	Orindiaçu
59370000	Fazenda Fortaleza	-22:57:36	-044:33:39	635	Mambucaba
59380000	Parati	-23:13:29	-044:45:41	79	Pereque-Açu

It should be noted that CPRM (2002) recommends that the Macabuzinho gaging station not be considered in regionalization studies of subbasin 59 because it presents a behavior different from the others, explained by the diversion of the river for power generation at the Macabu Small Hydroelectric Power Plant, located on Macabu River, municipality of Trajano de Morais, owned by the company Quanta Geração SA. Thus, the station was purged from Table 1.

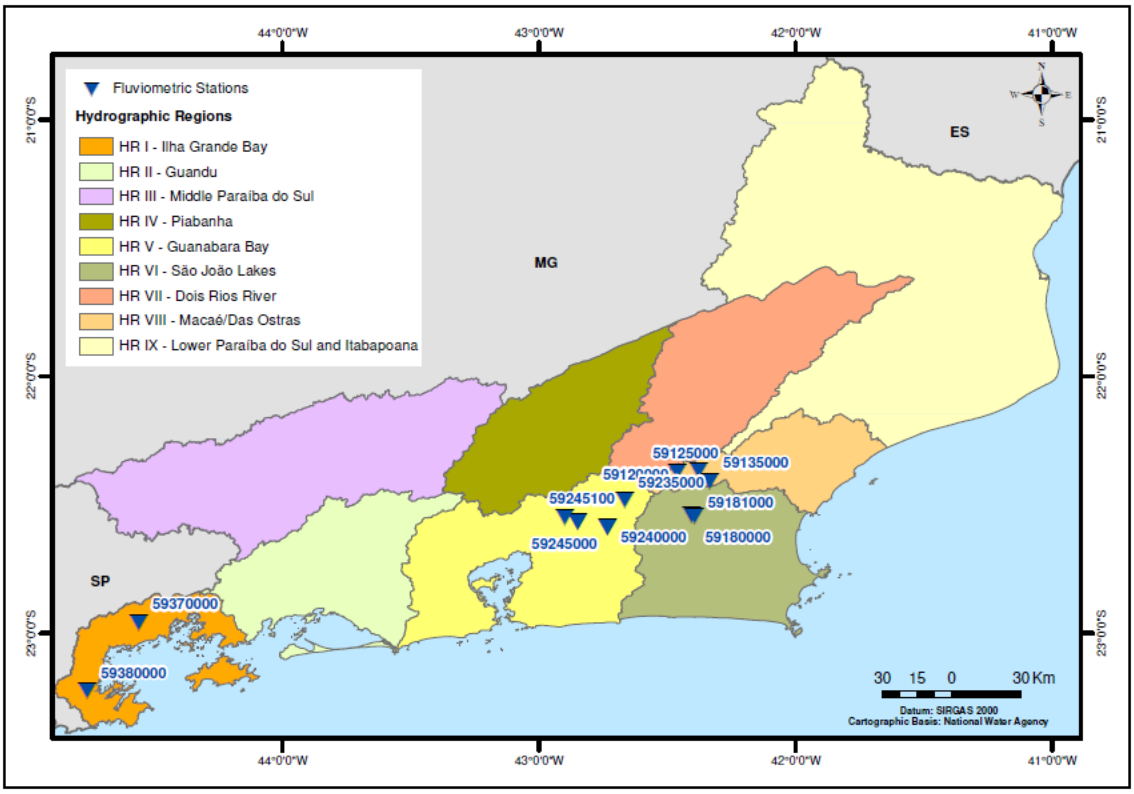
Table 2 consolidates the selected gaging stations, and Figure 2 shows their spatial distribution in subbasin 59.

Table 2. Selected gaging stations.

Code	Observation period(1)	Failures observed
59120000	May/1967 to Dec/2014	May/67
59125000	Aug/1950 to Dec/2014	Aug/50
59135000	Aug/1950 to Dec/2014	Aug/50
59180000	May/1967 to Oct/1982	May/67
59181000	Nov/1982 to Dec/2014	Nov/82
59235000	Dec/1931 to Dec/1978	Oct/36, Dec/36, Jan/37, Dec/37, Feb/65 to Feb/66
59240000	Jul/1969 to Dec/2014	Jul/1969
59245000	Jul/1969 to Dec/1978	Jul/1969
59245100	Jul/1969 to Dec/1978	Jul/69, Sep/71, Jul/73, and Oct to Nov/74
59370000	Aug/1935 to Dec/2014	-
59380000	Aug/1962 to Dec/2014	Aug/62

(1) At the time of the study, the data from the gaging stations in operation ended in 2014.

Figure 2. Distribution of the selected gaging stations in subbasin 59.



For each selected station, the respective minimum $Q_{7,10}$ and $Q_{95\%}$ reference flows were calculated at the monthly and daily levels. For this purpose, the Hydro 1.4 software was used, a computational tool developed by ANA, entitled *Sistema para Gerenciamento de Dados Hidrometeorológicos* (Hidro), which includes features to assist users in their activities involving storage, consultation, management and analysis of hydrometeorological data (ANA, 2020).

One of the functionalities available in Hydro 1.4 is the estimation of reference flows, either by fitting the Weibull probability distribution and plotting position (PP) or by permanence in time (ANA, 2020).

According to Coelho Filho *et al*. (2015), the Weibull distribution is one of the main distribution functions used to estimate minimum flows. Also called Type III Extreme Distribution, it represents the lower part of the data and corresponds to the less frequent values (Leme & Chaudhry, 2005).

The Weibull distribution has two parameters, α and β, and has the cumulative probabilities function given by Equation (1). The flows are fitted based on the calculation of the Q_7 flow, which represents the lowest moving average of 7 consecutive days for each year of the historical series under study and is calculated from a series of average daily flow rates (Santos *et al*., 2011).

$$F(x) = 1 - e^{-(x/\beta)^{\alpha}} \quad (1)$$

Parameters α and β correspond, respectively, to the shape and scale parameters and can be estimated by calculating the coefficient of variation (CV), expressed by:

$$CV = \frac{s}{\bar{x}} \quad (2)$$

The standard deviation (s) and the mean ($\bar{x}$) are calculated from the series of the lowest mean streamflow over seven consecutive days (Q_7) (Von Sperling, 2007).

The parameters of the Weibull distribution are determined from Equations (3), (4) and (5) (Von Sperling, 2007):

$$\alpha = 1.0122\, .\, CV^{-1.0779}, \text{ with } R^2 = 0.9998 \quad (3)$$

$$A(\alpha) = 0.9982 - 0.4419\, .\, CV + 0.4360\, .\, CV^2 \text{ with } r^2 = 0.9972 \quad (4)$$

$$\beta = \frac{\bar{x}}{A(\alpha)} \quad (5)$$

With the values of the parameters α and β, it is possible to calculate the minimum flow rate for a given desired recurrence time (Tr) through the inversion of Equation (1). Thus, applying the Weibull probability distribution, X_t is calculated for the value of Q_7 corresponding to a 10-year return period ($Q_{7.10}$) (Von Sperling, 2007):

$$X_t = \beta[-\ln\left(1 - \frac{1}{T_r}\right)]^{1/\alpha} \quad (6)$$

PP can be used to compare two or more data distributions and to determine the goodness-of-fit of the values to a given probability distribution (Cavalcanti, 2014).

According to Yu & Huang (2001), many researchers have discussed the PP method over the last decades and proposed different equations for its estimation. The Hydro 1.4 software provides the PP of the minimum flows of 7 consecutive days (Q_7) using the Weibull equation expressed by:

$$q_i = \frac{i}{n+1} \quad (7)$$

where i corresponds to the position of the ith value in the sample and n is the total number of data points.

In the study of annual minimum flows, the hydrological series data should be arranged in ascending order. In this case, PP represents the probability of nonexceedance, i.e., the probability of a variable X being equal to or less than a given quantile x (Naghettini & Pinto, 2007).

Tr can be estimated by the inverse of the probability of nonexceedance, according to Naghettini & Pinto (2007):

$$\mathrm{Tr} = \frac{1}{q_i} \quad (8)$$

With respect to the permanence in time of the flows, the curve is defined from the relationship between the magnitude and the frequency of the flows of a river, presenting an estimate of the percentage of time in which a given flow is equaled or exceeded over a historical period (Vogel & Fennessey, 1994).

According to Eletrobras (2000), the method used to obtain the flow duration curve over time should seek to define flow class intervals, which can be established according to the magnitude of the flows under analysis, seeking a considerable amount of values that fall in each interval. The amplitude can be estimated by:

$$d = \frac{Q_{max} - Q_{min}}{Nc - 1} \quad (9)$$

where Qmax represents the maximum streamflow of the hydrological series in m³/s, Qmin is the minimum streamflow of the series in m³/s and Nc is the number of class intervals, obtained by Equation (11) (ELETROBRAS, 2000):

$$\mathrm{Nc} = 1 + 33 \,.\, \ln(\mathrm{n}) \quad (10)$$

where n is the total number of data points and ln is the natural logarithm.

The frequency of each class (fi) is calculated from the count of the number of streamflows in the interval. Adding the values of f_i, in decreasing streamflow order, it is possible to obtain the duration values d_i. Calculating the sum of the frequency values (Nv), Equation (11), the probability P_i of a streamflow Q exceeding or equal to Q_i can be obtained by Equation (12) (ELETROBRAS, 2000).

$$\mathrm{Nv} = \sum \mathrm{f_i} \quad (11)$$

$$\mathrm{P_i} = \frac{\mathrm{d_i}}{\mathrm{Nv}} \times 100 \quad (12)$$

3 RESULTS AND DISCUSSION

In addition to the $Q_{7,10}$ flow (fitted by the Weibull distribution and obtained by PP), the $Q_{95\%}$ flows were also evaluated at daily and monthly levels. Table 3 shows the results found.

Table 3. Reference flows of subbasin 59 stations

Code	$Q_{7,10}$ estimated by Weibull (m³/s)	$Q_{7,10}$ estimated by PP (m³/s)	Percent difference (%)	$Q_{95\%}$daily (m³/s)	$Q_{95\%}$monthly (m³/s)	Percent difference (%)
59120000	0.619	0.628	1.5	0.865	0.957	10.6
59125000	1.050	1.100	4.8	1.390	1.540	10.8
59135000	0.824	0.810	1.7	1.210	1.380	14.0
59180000	1.870	2.236	19.6	3.270	3.890	19.0
59181000	3.080	4.083	32.6	5.180	6.090	17.6
59235000	0.512	1.505	194.0	2.160	2.570	19.0
59240000	1.920	2.157	12.3	2.980	3.500	17.4
59245000	1.440	1.804	25.3	2.770	3.420	23.5
59245100	0.399	0.314	21.3	0.700	0.796	13.7
59370000	6.200	7.067	14.0	9.400	10.500	11.7
59380000	0.616	0.701	13.8	0.986	1.150	16.6

Next, simulations were performed to define the percentage of the $Q_{95\%}$ reference flow that best represents the MWA defined by SERLA (2007).

Based on the calculations performed, it was found that the best approximation for 50% of $Q_{7,10}$ corresponds to 30% of $Q_{95\%}$. Tables 4 and 5 present the calculated values.

Table 4. Comparison between 50% of $Q_{7,10}$ estimated by Weibull distribution and 30% of $Q_{95\%}$ on a daily and monthly level.

Code	50%$Q_{7,10}$ (Weibull) (m³/s)	30%$Q_{95\%}$ daily (m³/s)	30%$Q_{95\%}$ monthly (m³/s)	Percent difference (%)	
				50%$Q_{7,10}$ and 30%$Q_{95\%}$daily	50%$Q_{7,10}$ and 30%$Q_{95\%}$monthly
59120000	0.310	0.260	0.287	16.2	7.2
59125000	0.525	0.417	0.462	20.6	12.0
59135000	0.412	0.363	0.414	11.9	0.5
59180000	0.935	0.981	1.167	4.9	-24.8
59181000	1.540	1.554	1.827	0.9	18.6
59235000	0.256	0.648	0.771	153.1	201.2
59240000	0.960	0.894	1.050	6.9	9.4
59245000	0.720	0.831	1.026	15.4	42.5
59245100	0.200	0.210	0.239	5.3	19.7
59370000	3.100	2.820	3.150	9.0	1.6
59380000	0.308	0.296	0.345	4.0	12.0

Table 5. Comparison between 50% of $Q_{7,10}$ estimated by PP and 30% of $Q_{95\%}$ on a daily and monthly level.

Code	50%$Q_{7,10}$ (PP) (m³/s)	30%$Q_{95\%}$ daily (m³/s)	30%$Q_{95\%}$ monthly (m³/s)	Percent difference (%)	
				50%$Q_{7,10}$ and 30%$Q_{95\%}$daily	50%$Q_{7,10}$ and 30%$Q_{95\%}$monthly
59120000	0.314	0.260	0.287	17.4	8.6
59125000	0.550	0.417	0.462	24.2	16.0
59135000	0.405	0.363	0.414	10.4	2.2
59180000	1.118	0.981	1.167	12.3	4.4
59181000	2.041	1.554	1.827	23.9	10.5
59235000	0.753	0.648	0.771	13.9	2.5
59240000	1.078	0.894	1.050	17.1	2.6
59245000	0.902	0.831	1.026	7.9	13.8
59245100	0.157	0.210	0.239	33.7	52.1
59370000	3.534	2.820	3.150	20.2	10.9
59380000	0.351	0.296	0.345	15.6	1.6

Table 4 shows that the lowest percent difference is found when comparing the 50% of $Q_{7,10}$ values with the 30% of $Q_{95\%}$ values on a daily level. In absolute terms, the percent difference ranged from 0.9% to 153.1%.

Table 5 shows that the lowest percent difference corresponds to the 50% of $Q_{7,10}$ values compared to the 30% of $Q_{95\%}$ values on a monthly level. In absolute terms, the percent difference ranged from 1.6% to 52.1%.

Regarding the proposition of a new MWA for subbasin 59, it was observed that the best approximation of 50% of $Q_{7,10}$ corresponds to 30% of $Q_{95\%}$ at the monthly level. These results are in agreement with those reported by Novo & Hora (2019) when estimating the MWA in the Guapi-Macacu River subbasin located in the drainage basin of Guanabara Bay at gaging stations operated by INEA. The authors indicate that the lowest percent difference is found when comparing the statistically fitted 50% of $Q_{7,10}$ values and 30% of $Q_{95\%}$ values on a daily level, ranging from 1% to 146%. Regarding the analysis between $Q_{7,10}$ obtained by PP with 30% of $Q_{95\%}$, the authors define the best fit as the monthly level, with a percent difference ranging from 2% to 29%. The authors conclude by recommending the adoption of 30% of $Q_{95\%}$ as representative of the MWA in the Guapi-Macacu River subbasin.

Furthermore, it is worth noting that the state of Rondônia also adopts 30% of the Q95% as a granting criterion (Pereira *et al.*, 2014). According to RHA (2018), Rondônia is part of the Amazon Biome, the water availability is significantly higher than the demands for the different sectors, with no critical areas. The Amazon region is characterized by an extensive hydrographic network, with great water availability (ANA, 2015).

4 CONCLUSIONS

The calculation of $Q_{95\%}$ does not involve the application of a probability distribution to fit the results, being estimated directly from the observed streamflow series. Therefore, the proposal of a new MWA criterion based on the $Q_{95\%}$ flow can facilitate the calculations of water availability and make the INEA granting process easier to apply.

However, the PNRH establishes that water resource management must provide multiple uses and ensure water availability. So, considering the lack of hydrological information from subbasin 59 and, consequently, the relevance of adopting a more conservative criterion to avoid granting a water supply that does not exist in the hydrographic region, it is recommended that the INEA revise the MWA value to 30% of $Q_{95\%}$ estimated at the monthly level.

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