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CIÊNCIA e NATURA

ISSN 2179-460X
OPEN ACCESS

Ci. e Nat., Santa Maria, v. 45, e20, 2023 • https://doi.org/10.5902/2179460X65901
submitted: 23/05/2021 • approved: 12/06/2023 • Published: 11/10/2023

Geography

Estimation and regionalization of minimum reference streamflows in the Branco River basin, Roraima, Brazil, as a support for water resources management

Estimativa e regionalização de fluxos mínimos de referência na bacia do Rio Branco, Roraima, Brasil, como apoio à gestão de recursos hídricos

Thiago Barboza Ribeiro[I], Luana Lisboa[II], Carlossandro Carvalho de Albuquerque[I], Michel Castro Moreira[III], Eduardo Morgan Uliana[IV]

[I]University of the State of Amazonas, Manaus, Brazil
[II]Geological Survey of Brazil, Manaus, Brazil
[III]Federal University of Viçosa, Viçosa, Brazil
[IV]Federal University of Mato Grosso, Sinop, Brazil

ABSTRACT

The effective application of water use granting requires knowing the water supply in the basin to allow the management body to match the demands of different users with water availability. Thus, determining the minimum reference streamflows and their regionalization is essential for defining the grantable limits. This study aimed to estimate and regionalize the minimum reference streamflows $Q_{7,10}$, Q_{95}, and Q_{90}, with an annual and semiannual frequency, for the Branco River basin, Roraima, Brazil. The following procedures stood out among those carried out: the survey of historical series of existing streamflow data for the basin within the scope of the National Hydrometeorological Network; definition of the hydrological year and seasonal periods; estimation and regionalization of the minimum reference streamflows with an annual and semiannual frequency; and assessment of the impact of seasonality on granting the concession for water resources management in the Branco River basin. The minimum reference streamflows were estimated for thirteen streamflow gauge stations and two homogeneous regions were defined. Significant increases in the minimum reference streamflows were observed when considering the rainy period compared to the annual period. The adoption of the annual streamflow permanence Q_{95} and Q_{90} at the Caracaraí streamflow gauge station on the Branco River replacing $Q_{7,10}$ allowed an increase of 75.1% and 123.3%, respectively, in the streamflow that can be granted. The analysis of results showed that the flexibility of the granting criteria in adopting the seasonality in the water availability allows considerable increases in the grantable streamflow of the Branco River basin in the flood semester.

Keywords: Use granting; Water availability; Water seasonality; Minimum reference streamflows

RESUMO

Para a efetiva aplicação da outorga de uso da água é necessário conhecer a oferta hídrica da bacia, a fim de permitir que o órgão gestor compatibilize as demandas dos diversos usuários com a disponibilidade hídrica. Assim, a determinação das vazões mínimas de referência e sua regionalização é de grande importância para a definição dos limites outorgáveis. O objetivo do estudo foi estimar e regionalizar as vazões mínimas de referência $Q_{7,10}$, Q_{95} e Q_{90}, com periodicidade anual e semestral, para a bacia do rio Branco, Roraima. Dentre os procedimentos realizados se destacam: o levantamento das séries históricas de dados de vazões existentes para a bacia, no âmbito da Rede Hidrometeorológica Nacional (RHN); a definição do ano hidrológico e dos períodos sazonais; a estimativa e a regionalização das vazões mínimas de referência com periodicidade anual e semestral; e a avaliação do impacto da sazonalidade na concessão da outorga para a gestão de recursos hídricos da bacia do rio Branco. Foram estimadas as vazões mínimas de referência para treze estações fluviométricas e definidas duas regiões homogêneas. Conforme os resultados obtidos, constataram-se aumentos significativos nas vazões mínimas de referência ao se considerar o período chuvoso em comparação ao anual. Na estação de Caracaraí, no rio Branco, a adoção das vazões de permanência anuais Q_{95} e Q_{90}, em substituição a $Q_{7,10}$, permite, respectivamente, aumento de 75,1% e 123,3% na vazão passível de ser outorgada. A partir das análises dos resultados concluiu-se que a flexibilidade dos critérios de outorga adotando a sazonalidade na disponibilidade hídrica permite, no semestre de cheia, aumentos consideráveis da vazão outorgável da bacia do rio Branco.

Palavras-chave: Outorga de uso; Disponibilidade hídrica; Sazonalidade hídrica; Vazões mínimas de referência

1 INTRODUCTION

The effective implementation of the instrument for granting rights to use water resources requires knowing the hydrological behavior of drainage basins, especially in determining the minimum reference streamflows used in the granting analysis process (Fioreze; Oliveira, 2010). The minimum reference streamflows adopted for granting purposes by water resources management body, directly influence the total available to be granted and reflect the flexibility of the states and the union in granting their grants (Alves, 2022).

According to Marques *et al.* (2009), many management bodies in Brazil have adopted the minimum streamflow with seven-day duration and ten-year return period ($Q_{7,10}$) or streamflows associated with 95% (Q_{95}) or 90% (Q_{90}) permanence in time as reference values for the granting process, providing only a percentage of these minimum reference streamflows for the various uses.

Costa and Tybush (2015) explain that each State can establish different criteria for determining the minimum reference streamflow. The water use granting in the State of Roraima, where the water resources management body is the State Foundation for the Environment and Renewable Water Resources (Femarh), was established by State Law No. 547, of June 23, 2006.

According to Femarh (2016), the State of Roraima had 717 users of water resources by the end of 2015 in the Branco River basin, where the main state-owned watercourse is located in the State, most of them referring to the abstraction of surface water. Despite this considerable number of water users, there is an absence of criteria and studies in the State of Roraima for the application of the grant instrument or support the establishment of the minimum reference streamflow values for using surface water.

Moreira and Silva (2014) emphasize that the need to know the streamflow along the hydrographic network and the limited series of available streamflow data often prevent or hinder the realization of adequate water resources management. The streamflow regionalization technique is used to overcome the lack of hydrological information in places with little or no data availability (Moreira, 2006).

Flow regionalization in some cases becomes crucial, especially when the cost for implementation of hydrometric network to measure data becomes unfeasible. Additionally, the regionalization process improves the estimates of hydrologic variables and allows checking the consistency of hydrological data series (Silva *et al*., 2006; Novaes *et al*., 2007; Lopes *et al*., 2017).

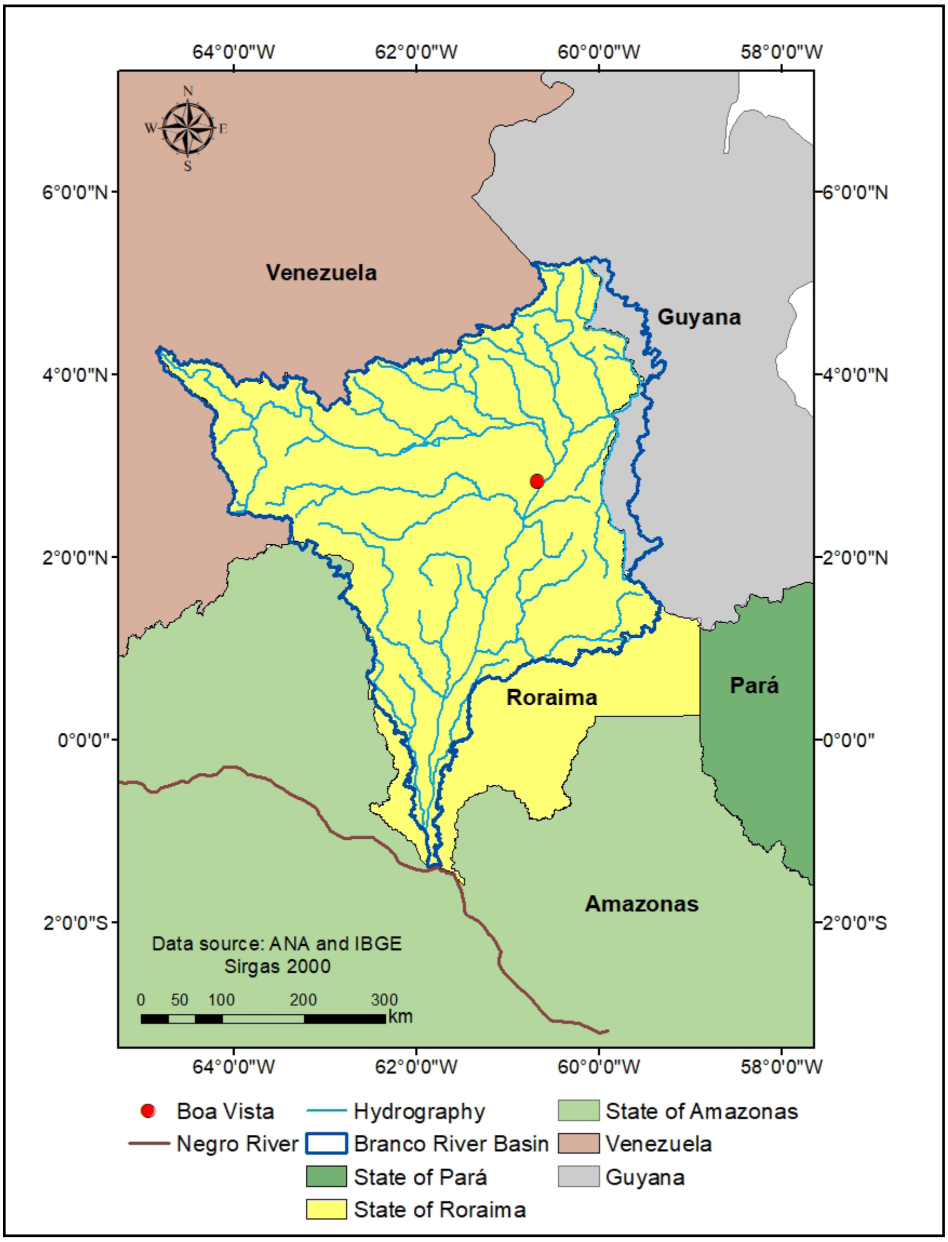
In this sense, this study aimed to estimate and regionalize the annual and semiannual minimum reference streamflows $Q_{7,10}$, Q_{95}, and Q_{90} for the Branco River basin, State of Roraima, Brazil, aiming to contribute to the process of granting rights to use water resources in the basin.

2 MATERIAL AND METHODS

2.1 Characterization of the study area

According to the Energy Research Company (EPE, 2011), the drainage basin of the Branco River (Figure 1) is located in the Amazon region, in the far north of Brazil, bordering Venezuela and occupying part of Guyana.

Figure 1 – Location of the drainage basin of the Branco River



Source: Authors' elaboration

According to Lisboa *et al.* (2015), the Branco River basin has a drainage area of 192,392 km^2, with the Branco River extending for 1,257 km from its formation, at the confluence of the Uraricoera and Tacutu Rivers, until its mouth on the left bank of the Negro River. The Branco River runs almost the entire length of the State of Roraima and receives its main tributary, the Tacutu River, about 30 km upstream of the city of Boa Vista.

Furthermore, the Mucajaí, Catrimani, Anauá, Água Boa do Univiní, Cauamé, Surumu, Cotingo, and Maú Rivers stand out among the tributaries of the Branco River.

The uses of water resources in the basin are concentrated in the northwest-southeast axis, in a range where there are no Indigenous Lands or Conservation Units. The main uses in the Branco River basin are characterized by public supply, irrigation, animal feed, fish farming, transport, tourism, and leisure (EPE, 2011).

The author also points out that the rainfall regime in the basin has three climate units: the Tropical Savanna Climate; the Tropical Monsoon Climate; and the Equatorial Tropical Climate.

2.2 Streamflow historical series

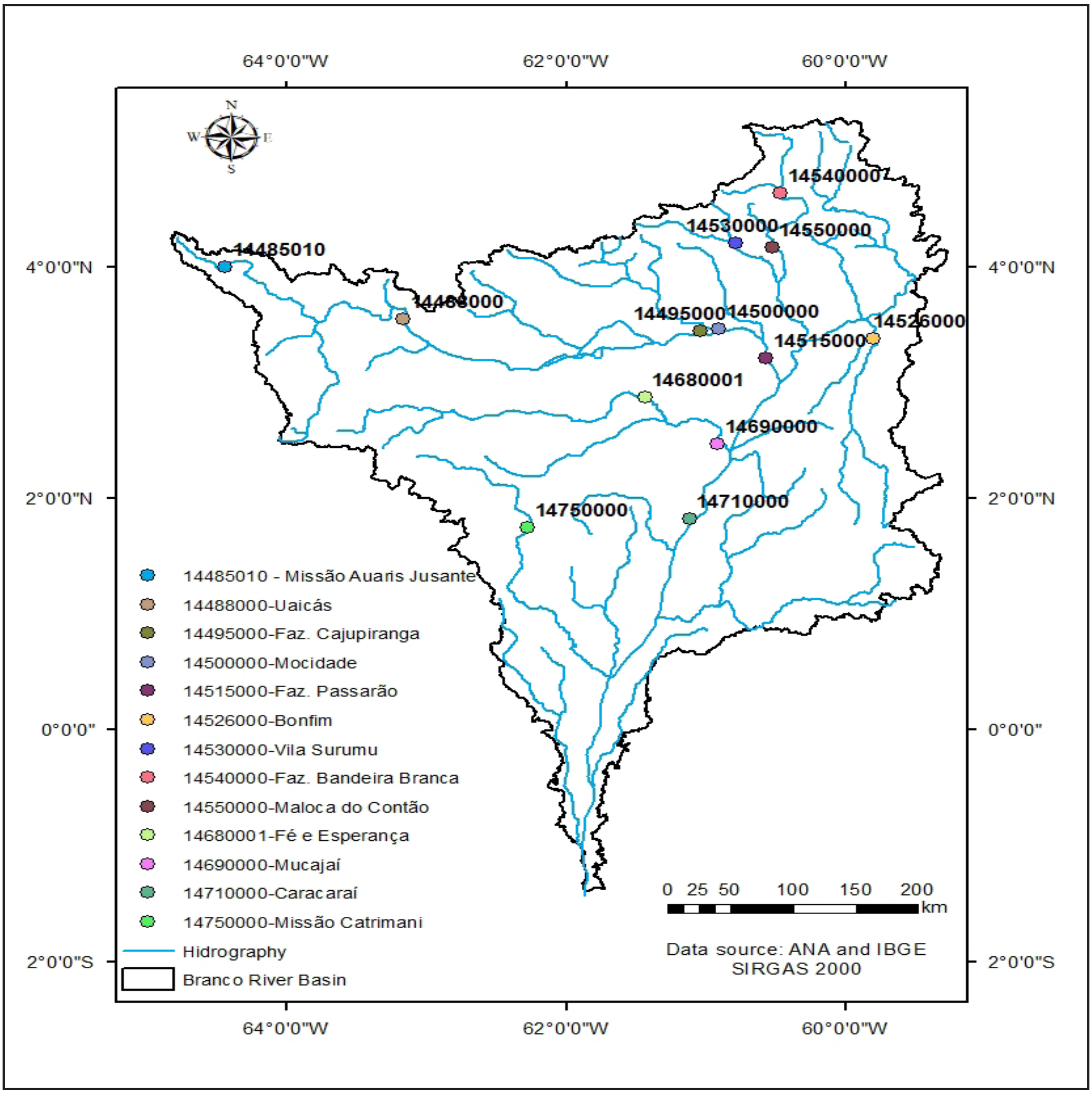
The survey of the quantity and quality of the streamflow data in the catchment area of the drainage basin was carried out from the inventory of the National Hydrometeorological Network (RHN), available through the Hydrological Information System Hidroweb (SIH/Hidroweb), from the National Water and Basic Sanitation Agency of Brazil (ANA) to estimate and regionalize the minimum streamflows.

Historical series of daily streamflows, with data from 13 streamflow gauge stations belonging to the Branco River basin (Figure 2 and Table 1) were used to determine the annual and semiannual minimum reference streamflows $Q_{7,10}$, Q_{95}, and Q_{90} for study area.

The software Hydrological Information System (SIH/Hidro v. 1.3), made available by ANA at Hidroweb's webpage, was used in the analysis and manipulation of the historical streamflow series.

Initially, a bar chart was elaborated for each station considering the annual period to define the period of data to be used. The association of the bar charts allowed defining the period of data in common between the streamflow gauge stations. In this sense, the base period of the study was defined from 1984 to 2014, featuring 30 years of hydrological data of daily streamflows.

Figure 2 – Streamflow gauge stations in the Branco River basin used in the study



Source: Authors' elaboration

Table 1– Streamflow gauge stations used in the study

Code	Name	Coordinates		River	Area(km²)
		Lat.(N)	***Long.(O)***		
14485010	*Missão Auaris - Jusante*	4.00	64.44	*Auaris*	621
14488000	*Uaicás*	3.55	63.17	*Uraricoera*	16,100
14495000	*Fazenda Cajupiranga*	3.44	61.04	*Uraricoera*	36,900
14500000	*Mocidade*	3.46	60.91	Uraricoera	43,900
14515000	*Fazenda Passarão*	3.21	60.57	*Uraricoera*	50,200
14526000	*Bonfim*	3.38	59.81	*Tacutu*	9,860
14530000	*Vila Surumu*	4.20	60.79	*Surumu*	2,280
14540000	*Fazenda Bandeira Branca*	4.63	60.47	*Cotingo*	3,210
14550000	*Maloca do Contão*	4.17	60.53	*Cotingo*	5,780
14680001	*Fé e Esperança*	2.87	61.44	*Mucajaí*	12,200
14690000	Mucajaí	2.47	60.92	*Mucajaí*	19,800
14710000	*Caracaraí*	1.82	61.12	*Branco*	126,000
14750000	*Missão Catrimani*	1.75	62.28	*Catrimani*	6,180

Source: Authors' elaboration

2.3 Definition of the hydrological year and seasonal periods

The hydrological year was determined to serve as a temporal basis for the estimation and regionalization of streamflows, replacing the calendar year. The determination of the hydrological year and semiannual periods (rainy and lowing) was performed based on the observation of the natural variability of the hydrological regime of the basin through the annual distribution of the minimum specific streamflows.

The determination of the hydrological year and seasonal periods in the Branco River basin required the identification of the months with homogeneous streamflow regimes by applying the methodology presented by Marques (2010), who proposed to define seasonal periods from the study of minimum specific streamflows.

2.4 Estimation and flexibility of annual and semiannual minimum reference streamflows

The historical series of minimum streamflows with a seven-day duration (q_7) was calculated for each streamflow gauge station to estimate $Q_{7,10}$. Probabilistic frequency distribution models were applied under the q_7 series to determine the ten-year return period.

The probability distributions usually applied in hydrology were adjusted to each q_7 series to represent minimal events, such as the Weibull, log-normal III, log-Gumbel, Pearson type III, and log-Pearson type III distributions. The best distribution was then selected considering the adherence of the theoretical probability model to the sample data.

The streamflows associated with the 90% (Q_{90}) and 95% (Q_{95}) permanence for the streamflow gauge station were estimated from the permanence curve for all historical series used in the study.

In addition to the estimates of the streamflows $Q_{7,10}$, Q_{90}, and Q_{95} for the annual period, the minimum streamflows were also estimated considering the seasonal periods (flood and lowing semesters).

The Computational System for Hydrological Analysis (SisCAH 1.0), developed by the Water Resources Research Group (GPRH) of the Federal University of Viçosa (UFV), available at www.ufv.br/dea/gprh, was used to estimate the annual and semiannual streamflows $Q_{7,10}$, Q_{90}, and Q_{95}.

The seasonal flexibility of $Q_{7,10}$, Q_{95}, and Q_{90} was evaluated by comparing the estimated values based on the annual period with those estimated on a semiannual basis (flood and lowing). The percentage difference (PD) was used in this comparison, considering the estimate of the minimum reference streamflows of the semiannual periods with the annual period, according to the equation:

$$PD\,(\%) = \frac{(Q_{seasonal} - Q_{annual})}{Q_{annual}} x100 \quad (1)$$

where $Q_{seasonal}$ is the estimated streamflow on a seasonal basis and Q_{annual} is the estimated streamflow on an annual basis, both in $m^3\,s^{-1}$.

2.5 Regionalization of annual and semiannual minimum reference streamflows

The regionalization of the annual and semiannual minimum reference streamflows ($Q_{7,10}$, Q_{95}, and Q_{90}) was performed using the streamflow regionalization technique described by Eletrobras (1985), which consists of the identification of hydrologically homogeneous regions and determination of regional regression equations that allow obtaining streamflows at any position of the drainage network in a basin. The choosing the hydrologically homogeneous regions based on the location and availability of existing fluviometric stations in the basin, in the consistency of historical series, and basead on the statistical results for the determination coefficients (R^2), the standard error of the estimative.

An iterative process was used to determine hydrologically homogeneous regions (HHR). Subsequently, regionalization equations were determined for the annual and semiannual minimum reference streamflows ($Q_{7,10}$, Q_{95}, and Q_{90}) through functions that relate each reference streamflow with the hydrological variable drainage area (Ad). In this sense, the following regression models (Equations 2 to 6) were used with the respective independent variable:

Linear model

$$Q = \beta_0 + \beta_1.Ad \tag{2}$$

Potential model

$$Q = \beta_0.Ad^{\beta_1} \tag{3}$$

Exponential model

$$Q = e^{(\beta 0 + \beta 1.Ad)} \tag{4}$$

Logarithmic model

$$Q = \beta_0 + \beta_1.lnAd \tag{5}$$

Reciprocal model

$$Q = (\beta_0 + \beta_1.Ad)^{-1} \quad (6)$$

where Q is the streamflow to be estimated ($m^3 s^{-1}$), Ad is the drainage area (km^2), and β_0 and β_1 represent the multiple regression coefficients (dimensionless).

The computer program SisCoRV (Sistema Computacional para Regionalização de Vazões), developed by GPRH/UFV, was used in the regionalization of streamflows in the basin.

3 RESULTS AND DISCUSSION

3.1 Hydrological year and seasonal periods

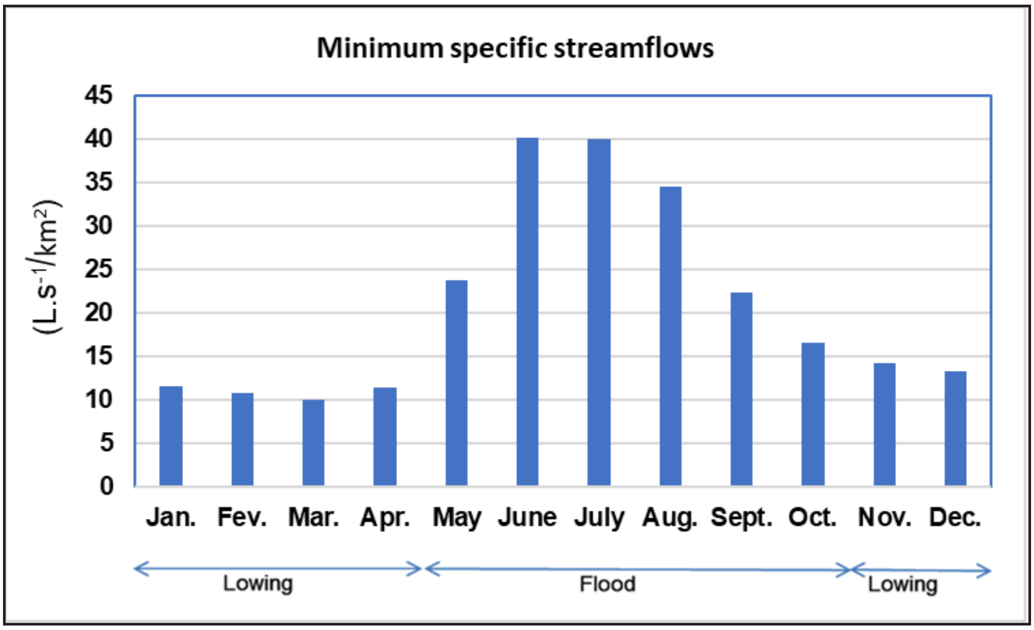
The distributions of the mean monthly minimum specific streamflows for the 13 streamflow gauge stations used in the study were determined aiming to apply the principles of identification of seasonal periods (flood and lowing semesters) and the hydrological year for the Branco River basin, as shown in Figure 3.

Figure 3 shows that the amplitude of means of the minimum specific streamflows ranged from 10.0 to 40.2 L s^{-1}/km^2, which were observed in March and June, characterizing the months with minimum and maximum water availability for the basin, respectively.

The increase in the minimum streamflow values occurred from May. Thus, the beginning of the hydrological year was defined in May, extending until April of the following year. The streamflow analyses were carried out considering the hydrological year instead of the calendar year to avoid the discontinuity of flood and lowing events in the basin.

Figure 3 also shows the two seasonal periods of water availability for the Branco River basin, that is, the flooding semester, with the highest values for the minimum specific streamflows, extending from May to October, and the lowing semester, which extends from November to April of the following year.

Figure 3 – Distribution of means of the monthly minimum specific streamflows used in the study



Source: Authors' elaboration

The q_7 variation between periods was an indication of the flexibility of the reference streamflows intended with the adoption of seasonal periods as an alternative to the annual period. On average, the minimum streamflows with a seven-day duration in the lowing period are virtually the same as q_7 when adopting the annual period. Small variations were observed due to the rare years in which the seven most critical days did not occur during the lowing period. The minimum streamflows of the lowing and flood periods are, on average, 4.73% and 130.33% higher than the annual period, respectively.

Table 2 shows the frequency of occurrence of the seven consecutive days with the lowest observed streamflows (q_7) in months and periods with homogeneous trends of water availability (flood and lowing).

The monthly analysis of the frequency of occurrence of q_7 confirmed the classification of months in the trends of minimum or maximum water availability for the hydrological regime of the drainage basin of the Branco River, as the frequency of occurrence of q_7 is 90.22% concentrated from November to April and less than 10% of the minimum streamflows occur between May and October, defined as the flooding semester.

Table 2 – Frequency of occurrence of the annual q7 in periods with homogeneous trends

Period	Month	No. occurrences	%	% in the period
Flood	May	23	8.65	9.78
	June	0	0.00	
	July	0	0.00	
	Aug.	0	0.00	
	Sept.	0	0.00	
	Oct.	3	1.13	
Lowing	Nov.	2	0.75	90.22
	Dec.	16	6.01	
	Jan.	23	8.65	
	Feb.	39	14.66	
	Mar.	88	33.08	
	Apr.	72	27.07	
Total		266	100.0	100.0

Source: Authors' elaboration

3.2 Estimation and flexibility of annual and semiannual minimum reference streamflows

Table 3 shows the annual minimum reference streamflows $Q_{7,10}$, Q_{95}, and Q_{90} for the streamflow gauge station belonging to the Branco River basin, RR, Brazil.

Table 3 shows that the values of minimum permanence streamflows (Q_{95} and Q_{90}) are considerably higher than $Q_{7,10}$, which is of a lower magnitude and, thus, more restrictive in the sense of using it as a reference for water use aiming at granting purposes.

The estimates of annual minimum streamflows showed the $Q_{7,10}$ ranged from 0.94 $m^3 s^{-1}$ at the Bonfim station (14526000) to 252.67 $m^3 s^{-1}$ at the Caracaraí station (14710000), while Q_{95} and Q_{90} ranged from 1.5 to 443.23 $m^3 s^{-1}$ and 1.75 to 564.95 m^3

s^{-1}, respectively. Very low values of estimated streamflow were observed at the Bonfim station ($Q_{7,10}$ = 0.94 m^3 s^{-1}) compared to the streamflow of the 1453000 station (Vila Surumu), which presented a value of 2.54 m^3 s^{-1} (170 % higher), but has a lower drainage area of 2,280 km^2, corresponding to approximately four times the drainage area of the Bonfim station.

Another example is the $Q_{7,10}$ value of 8.59 m^3 s^{-1} presented at station 14750000 (Missão Catrimani), which has a drainage area of 6,100 km^2, corresponding to more than 50% of the Bonfim station area, with streamflow almost 10 times higher.

Table 3 – Annual and semiannual minimum reference streamflows $Q_{7,10}$, Q_{95}, and Q_{90} (m^3 s^{-1}) in the Branco River basin, RR, Brazil

Code	Ad*	Annual			Lowing semester			Flood semester		
		$Q_{7,10}$	Q_{95}	Q_{90}	$Q_{7,10}$	Q_{95}	Q_{90}	$Q_{7,10}$	Q_{95}	Q_{90}
14485010	621	7.99	12.15	15.65	8.46	9.66	11.60	13.59	19.46	22.21
14488000	16.100	146.17	208.00	234.00	143.44	182.00	202.00	219.79	294.12	356.00
14495000	36.900	97.20	227.31	299.15	96.40	168.56	231.13	287.90	484.13	625.03
14500000	43.900	102.81	256.00	356.00	102.81	184.00	256.00	365.69	540.00	689.50
14515000	50.200	149.06	282.13	358.83	152.97	232.33	285.81	367.44	614.51	779.83
14526000	9.860	0.94	1.50	1.75	1.00	1.38	1.56	1.25	6.74	15.78
14530000	2.280	2.54	4.53	6.63	2.68	4.42	4.53	5.03	12.57	15.66
14540000	3.210	5.09	13.00	17.00	5.56	9.80	13.40	11.46	25.40	34.10
14550000	5.780	9.48	17.39	21.73	9.13	14.52	17.39	23.23	36.50	47.04
14680001	12.200	30.55	62.60	80.60	30.13	50.60	63.80	91.08	146.00	184.40
14690000	19.800	35.72	85.53	134.87	33.47	56.32	82.81	188.38	252.28	333.69
14710000	126.000	252.67	443.26	564.94	261.70	367.11	448.54	627.95	1025.24	1342.64
14750000	6.180	8.59	21.26	27.64	9.04	16.36	21.60	36.34	69.00	85.72

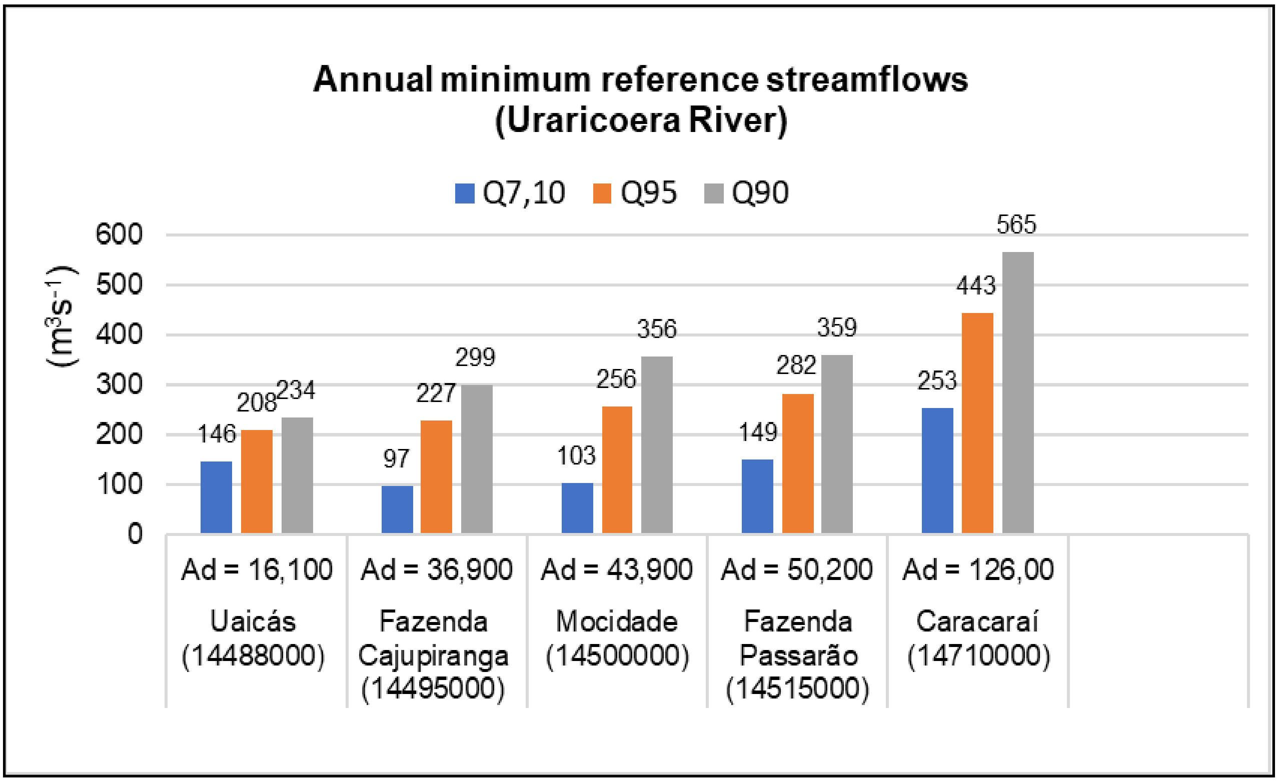
*Ad – Drainage area (km^2)

Source: Authors' elaboration

Figure 4 shows the annual minimum reference streamflows ($Q_{7,10}$, Q_{95}, and Q_{90}) considering the drainage area of the existing streamflow gauge stations along the Uraricoera River (Branco), allowing a better interpretation of the streamflow estimates.

Figure 4 shows that the minimum permanence flows (Q_{95} and Q_{90}) increased as the drainage area increased, thus characterizing the continuity of streamflows along the Uraricoera River (Branco). However, the difference is only 3 m^3 s^{-1} for a variation in the drainage area of 43,900 to 50,200 km^2 at the Mocidade and Fazenda Passarão stations.

Figure 4 – Annual minimum reference streamflows $Q_{7,10}$, Q_{95}, and Q_{90} as a function of the drainage area of the existing streamflow gauge station along the Uraricoera River (Branco)



Source: Authors' elaboration

This behavior was not observed for $Q_{7,10}$ at the Uaicás station (14488000), as the estimated minimum reference streamflow (146 $m^3 s^{-1}$) was higher than the streamflows of stations located downstream, such as Fazenda Cajupiranga (14459000) and Mocidade (14500000), which showed estimated values of 97 and 103 $m^3 s^{-1}$, respectively. The $Q_{7,10}$ of the Uaicás station was surpassed at the Fazenda Passarão station (14515000), with a drainage area of 50,200 km^2.

The analysis of the magnitude of the minimum streamflows estimated for adoption by the State water resources management agency showed that the annual permanence streamflows Q_{95} and Q_{90} as reference streamflow replacing $Q_{7,10}$ increased by 75.1% and 123.3% the streamflow that can be granted to water users, respectively, considering the Caracaraí station (14710000) on the Branco River.

The adoption of minimum reference streamflows $Q_{7,10}$, Q_{95}, and Q_{90} at the Caracaraí station (14710000) in the rainy period replacing the minimum reference streamflows considering an annual periodicity allows percentage increases of 148.2, 131.3, and 137.6%, respectively, in the streamflow available for grants from May to October (flood semester).

Considering an increase in availability because permanence streamflows have values considerably higher than $Q_{7,10}$, allowing a significant increase in the streamflow that can be granted by users in the Branco River basin, the use of these streamflows as a reference in the analysis of grant requests evaluated by the water resources management body is recommended, as $Q_{7,10}$ did not show continuity of streamflows in the region close to the spring (Uaicás) of the Uraricoera River.

Another fact that justifies the use of permanence streamflows is related to the low $Q_{7,10}$ values estimated at some stations in the Branco River basin, which makes the granted streamflows very restrictive for the various users, such as the Bonfim station, among others.

Table 4 shows the mean percentage difference of minimum seasonal reference streamflows relative to the annual streamflow. No significant flexibility was observed when considering the $Q_{7,10}$ of the dry period because the annual q_7 occurred out of this period rarely. Therefore, there were situations in which the $Q_{7,10}$ for the dry period was higher than the $Q_{7,10}$ for the annual period.

Table 5 – Mean percentage difference of the minimum seasonal reference streamflows $Q_{7,10}$, Q_{95}, and Q_{90} relative to the annual

Reference streamflow	**Mean seasonal flexibility (%)**	
	Lowing semester	**Flood semester**
$Q_{7,10}$	0.94	163.80
Q_{95}	-20.65	115.70
Q_{90}	-22.59	113.88

Source: Authors' elaboration

Considering the permanence streamflows Q_{95} and Q_{90}, the negative flexibility in the semiannual lowing period occurred because the streamflow values of the rainy period are included in the annual periodicity of the permanence curves, increasing the values for this period. Therefore, the reference streamflows for the dry period decrease when the semester is adopted to the detriment of the annual period.

Table 5 shows that the use of seasonal periods to determine reference streamflows for the drainage basin of the Branco River increases the flexibility of water availability for granting.

These results corroborate with those obtained by several authors who applied the same concept, such as Lisboa *et al.* (2014), Marques (2010), Silva; Silva; Moreira (2015), and Silva; Marques; Lemos (2011). As in the present study, these authors observed an increase in the percentage of the use of the seasonal streamflow in periods of higher water supply (rainy/flood) compared to the corresponding annual streamflow.

3.3 Regionalization of annual and semiannual minimum reference streamflows

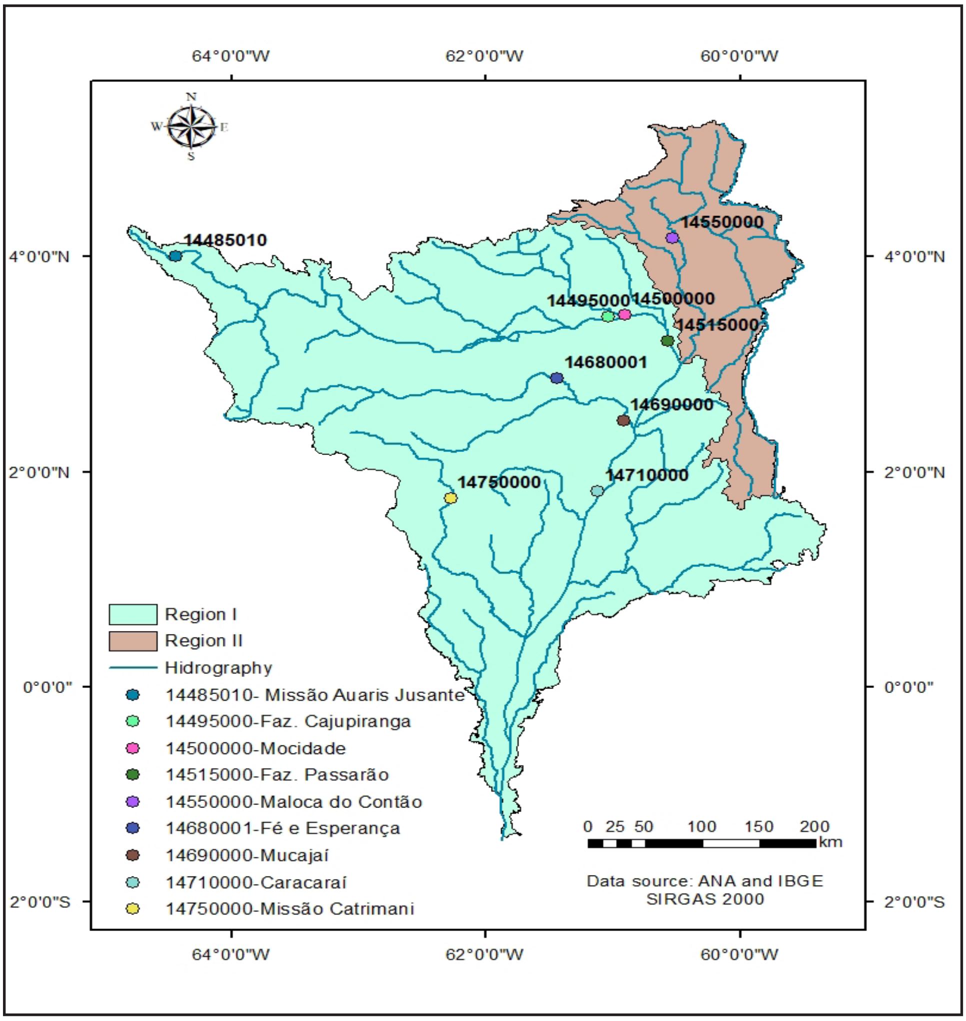
A limited number of streamflow gauge stations distributed is found in the large territorial dimension of the Branco River basin, which makes the drainage area the main physical characteristic to be used in the regression adjustments to determining the regionalization equations. It also limited the number of hydrologically homogeneous regions determined within the basin.

There is only one streamflow gauge station with daily streamflow data (Caracaraí – 14710000) in the Branco River (after the confluence of the Uraricoera River with the Tacutu River). The streamflow gauge stations of Boa Vista (14620000) and Santa Maria do Boiaçu (14790000) are in the same watercourse and present only elevation information among other hydrological data.

We opted for removing the Bonfim (14526000) and Missão Catrimani (14750000) during the process of determining the hydrologically homogeneous regions and regionalization equations. These streamflow gauge stations showed inconsistent values in the estimation of minimum streamflows, which impaired the quality of regionalization. The Uaicás station (14489000) was also removed from the regionalization process since the estimated streamflow values were higher than those of the downstream stations.

The best fit in the identification of homogeneous regions in the Branco River basin considered two homogeneous regions, divided according to the information from the Tacutu and Uraricoera River basins, totaling nine streamflow gauge stations used for regionalization (Figure 5). Thus, two hydrologically homogeneous regions were defined, and regional regression equations were established for each one.

Figure 5 – Hydrologically homogeneous regions and streamflow gauge stations used in the regionalization



Source: Authors' elaboration

Table 6 shows the results of the regionalization equations obtained for the annual and semiannual minimum streamflow $Q_{7,10}$ (lowing and rainy), as well as the regression coefficient and the percentage error between observed values and those estimated by the regionalization equation.

The best results described were selected considering the highest values of the coefficient of determination (R^2) and the lowest residual values, through the percentage error between the observed values and the estimated values for each regression model.

Table 6 shows that the distribution model that showed the best results for the minimum reference streamflow $Q_{7,10}$ was the potential, with coefficients of determination (R^2) higher than 0.87 for all the obtained equations.

The percentage errors between the observed streamflows and those estimated by the regionalization model for the annual period underestimated the streamflows at the Fazenda Cajupiranga, Mocidade, and Fazenda Passarão stations (Region I) and Fazenda Bandeira Branca station (Region II), varying from −9.95% to −19.06%. The Caracaraí station is located further downstream in the Branco River basin and its observed and estimated streamflows (annual $Q_{7,10}$ Annual) are, respectively, 252.67 and 306.84 $m^3 s^{-1}$, resulting in an error of estimate of 21.44%.

The potential model for the adjusted annual $Q_{7,10}$ overestimated the streamflows at the Fé e Esperança, Mucajaí, and Caracaraí stations (Region I) and Vila Surumu, Fazenda Bandeira Branca, and Maloca do Contão stations (Region II), varying from 1.81% in Fé e Esperança to 26.28% in Mucajaí, located in the same watercourse. The errors increased, with also an increase in the drainage area, both in the Uraricoera – Branco River (Fazenda Cajupiranga, Mocidade, Fazenda Passarão, and Caracaraí), and in the Mucajaí River (Fé e Esperança and Mucajaí), located in the same homogeneous region (Region I).

The observed and estimated streamflows presented results similar to those obtained for the annual period when considering the lowing period, with no significant differences.

The estimated streamflows for the flood period through the regionalization equations for Regions I and II showed errors ranging from 23.30 to 33.38% for the Mocidade and Fé e Esperança stations on the Uraricoera and Mucajaí Rivers, respectively, with values similar to those obtained for the errors of the annual period. The smallest percentage error between streamflow values was observed in the *Fazenda Passarão* station (2.41%).

Table 6 – Regionalization equations for the minimum streamflows $Q_{7,10}$ (m^3 s^{-1}) considering the annual and semiannual period (lowing and flood), observed and estimated streamflow values, and the percentage error of the estimate for the streamflow gauge stations

(continued)

Annual $_{Q7,1}$**0**							
Homogeneous region	**Streamflow gauge station**		**Adjustment**		**Streamflow (m^3 s^{-1})**		**PE*** **
			Model	**R^2**	**Obs.***	**Est.****	
Region I	14495000	*Fazenda Cajupiranga*	*Potential*	0.95	97.20	88.21	−9.25
	14500000	*Mocidade*			102.81	89.08	−13.35
	14515000	*Fazenda Passarão*			149.06	121.42	−18.54
	14680001	*Fé e Esperança*			30.55	31.10	1.81
	14690000	*Mucajaí*			35.72	45.11	26.28
	14710000	*Caracaraí*			252.67	306.84	21.44
	Annual $Q_{7,10} = 1.65\times10^{-3}\ Ad^{1.034}$						
Region II	14530000	*Vila Surumu*	*Potential*	0.92	2.54	2.96	16.65
	14540000	*Fazenda Bandeira Branca*			5.09	4.12	−19.03
	14550000	*Maloca do Contão*			9.48	10.04	5.88
	Annual $Q_{7,10} = 5.53\times10^{-5}\ Ad^{1.397}$						
Lowing $Q_{7,10}$							
Homogeneous region	**Streamflow gauge station**		**Adjustment**		**Streamflow (m^3 s^{-1})**		**PE*** **
			Model	**R^2**	**Obs.***	**Est.****	
Region I	14495000	*Fazenda Cajupiranga*	*Potential*	0.95	96.40	87.89	−8.82
	14500000	*Mocidade*			102.81	88.79	−13.63
	14515000	*Fazenda Passarão*			152.97	122.32	−20.04
	14680001	*Fé e Esperança*			30.13	29.90	−0.75
	14690000	*Mucajaí*			33.47	43.92	31.23
	14710000	*Caracaraí*			261.70	319.11	21.94
	Lowing $Q_{7,10} = 1.13\times10^{-3}\ Ad^{1.069}$						
Region II	14530000	*Vila Surumu*	*Potential*	0.87	2.68	3.21	19.84
	14540000	*Fazenda Bandeira Branca*			5.56	4.34	−21.97
	14550000	*Maloca do Contão*			9.13	9.76	6.94
	Lowing $Q_{7,10} = 1.57\times10^{-4}\ Ad^{1.273}$						

Table 6 – Regionalization equations for the minimum streamflows $Q_{7,10}$ ($m^3\ s^{-1}$) considering the annual and semiannual period (lowing and flood), observed and estimated streamflow values, and the percentage error of the estimate for the streamflow gauge stations

(Conclusion)

Flood $Q_{7,10}$								
Homogeneous region	**Streamflow gauge station**		**Adjustment**		**Streamflow ($m^3\ s^{-1}$)**		**PE*** **
			Model	**R^2**	**Obs.***	**Est.****	
Region I	14495000	*Fazenda Cajupiranga*	*Potential*	0.91	287.90	278.30	−3.33
	14500000	*Mocidade*			365.69	280.49	−23.30
	14515000	*Fazenda Passarão*			367.44	358.58	−2.41
	14680001	*Fé e Esperança*			91.08	121.76	33.68
	14690000	*Mucajaí*			188.38	163.50	−13.21
	14710000	*Caracaraí*			627.95	747.97	19.11
	Flood $Q_{7,10} = 4.95\times10^{-2}\ Ad^{0.820}$						
Region II	14530000	*Vila Surumu*	*Potential*	0.91	5.03	6.06	20.46
	14540000	*Fazenda Bandeira Branca*			11.46	8.88	−22.52
	14550000	*Maloca do Contão*			23.23	24.89	7.14
	Flood $Q_{7,10} = 2.02\times10^{-5}\ Ad^{1.618}$						

*Observed $Q_{7,10}$ values; **Values estimated by the regionalization model; ***Percentage error

Source: Authors' elaboration

Table 7 shows the regionalization equations for the minimum streamflows Q_{95} ($m^3\ s^{-1}$) considering the annual and semiannual period (lowing and flood), as well as the observed and estimated streamflow values and the percentage error of the estimate for the streamflow gauge stations in the two homogeneous regions.

Considering the results shown in Table 7 for the minimum reference streamflow Q_{95}, the potential mathematical model fitted better to the estimated streamflows for the stations under study, with coefficients of determination (R^2) ranging from 0.70 for Region II (annual period) to 0.94 for Region I (flood period).

The percentage error of the estimate of Q_{95} in the annual period ranged from −25.93 to 30.37% at Mocidade and Caracaraí stations for Region I, both stations located on the Uraricoera River (Branco). The errors for Region II varied from 12.34% at Maloca do Contão station to 36.85% at Vila Surumu station. The mean percentage error considering the modulus of values is 20.37% in Region I and 28.05% in Region II.

The errors of the estimate of Q_{95} during the lowing period varied from −21.49 to 34.14% at Mocidade and Mucajaí stations for Region I and Region II, respectively, and −25.59 to 24.07% at Bandeira Branca and Vila Surumu stations, respectively. Therefore, the Vila Surumu station presented the highest estimation errors by the regionalization model in Region II, corresponding to the station with the smallest drainage area.

The streamflows at the Mocidade station were underestimated for both the annual and lowing periods, a behavior also observed during the flood period in the basin and equal to −18.71%, that is, the highest underestimations in the streamflows were found in this station. The streamflow determined at Fazenda Cajupiranga and Fazenda Passarão stations were also underestimated by the regionalization models in the three analyzed periods (annual, flood, and lowing), as well as for Fazenda Bandeira Branca station, in Region II.

In general, the lowest errors in estimating Q_{95} by the regionalization equations were observed during the flood period, as they ranged from −18.71 to 24.10% in Region I and −22.78 to 20.76% in Region II.

The estimate of streamflows through the regionalization equations for Region II during the flood period showed errors ranging from −1.82 to 24.10% for Mucajaí and Fé e Esperança stations, respectively, characterizing the lowest and highest percentage error for this period.

Table 7 – Regionalization equations for the minimum streamflows Q_{95} ($m^3 s^{-1}$) considering the annual and semiannual periods (lowing and flood), as well as the observed and estimated streamflow values and the percentage error of the estimate for the streamflow gauge stations in the two homogeneous regions

(Continued)

Annual Q_{95}

Homogeneous region	Streamflow gauge station		Adjustment		Streamflow ($m^3 s^{-1}$)		PE***
			Model	R^2	Obs.*	Est.**	
Region I	14495000	*Fazenda Cajupiranga*	*Potential*	0.91	227.31	187.95	-17.31
	14500000	*Mocidade*			256.00	189.63	-25.93
	14515000	*Fazenda Passarão*			282.13	250.66	-11.16
	14680001	*Fé e Esperança*			62.60	73.48	17.38
	14690000	*Mucajaí*			85.53	102.71	20.09
	14710000	*Caracaraí*			443.26	577.87	30.37
	Annual $Q_{95} = 1.03x10^{-2}\,Ad^{0.932}$						
Region II	14530000	*Vila Surumu*	*Potential*	0.70	4.53	6.20	36.85
	14540000	*Fazenda Bandeira Branca*			13.00	8.46	-34.95
	14550000	*Maloca do Contão*			17.39	19.54	12.34
	Annual $Q_{95} = 2.21x10^{-4}\,Ad^{1.314}$						

Lowing Q_{95}

Homogeneous region	Streamflow gauge station		Adjustment		Streamflow ($m^3 s^{-1}$)		PE***
			Model	R^2	Obs.*	Est.**	
Region I	14495000	*Fazenda Cajupiranga*	*Potential*	0.92	168.56	143.11	-15.10
	14500000	*Mocidade*			184.00	144.46	-21.49
	14515000	*Fazenda Passarão*			232.33	194.02	-16.49
	14680001	*Fé e Esperança*			50.60	53.03	4.79
	14690000	*Mucajaí*			56.32	75.55	34.14
	14710000	*Caracaraí*			367.11	469.16	27.80
	Lowing $Q_{95} = 4.49x10^{-3}\,Ad^{0.985}$						
Region II	14530000	*Vila Surumu*	*Potential*	0.81	4.42	5.48	24.07
	14540000	*Fazenda Bandeira Branca*			9.80	7.29	-25.59
	14550000	*Maloca do Contão*			14.52	15.73	8.32
	Lowing $Q_{95} = 4.52x10^{-4}\,Ad^{1.206}$						

Table 7 – Regionalization equations for the minimum streamflows Q_{95} ($m^3\ s^{-1}$) considering the annual and semiannual periods (lowing and flood), as well as the observed and estimated streamflow values and the percentage error of the estimate for the streamflow gauge stations in the two homogeneous regions

(Conclusion)

Flood Q_{95}							
Homogeneous region	Streamflow gauge station		Adjustment		Streamflow ($m^3\ s^{-1}$)		PE***
			Model	R^2	Obs.*	Est.**	
Region I	14495000	Fazenda Cajupiranga	Potential	0.94	484.13	435.34	-10.08
	14500000	Mocidade			540.00	438.97	-18.71
	14515000	Fazenda Passarão			614.51	569.56	-7.32
	14680001	Fé E Esperança			146.00	181.19	24.10
	14690000	Mucajaí			252.28	247.68	-1.82
	14710000	Caracaraí			1025.24	1241.98	21.14
	Flood $Q_{95} = 4.60x10^{-2}\ Ad^{0.869}$						
Region II	14530000	Vila Surumu	Potential	0.82	12.57	15.18	20.76
	14540000	Fazenda Bandeira Branca			25.40	19.61	-22.78
	14550000	Maloca do Contão			36.50	39.14	7.24
	Flood $Q_{95} = 3.23x10^{-3}\ Ad^{1,085}$						

*Observed Q_{95} values; **Values estimated by the regionalization model; ***Percentage error

Source: Authors' elaboration

Table 8 shows the regionalization equations for the annual and semiannual minimum streamflows Q_{90} (lowing and rainy), as well as the regression coefficient and the percentage error between the observed and estimated values.

According to the results shown in Table 8, the potential model presented the best results for the minimum streamflow Q_{90}, and the coefficient of determination (R^2) for the equations obtained in the regionalization process ranged from 0.68 (lowing period, Region II) to 0.94 (flood period, Region I).

The percentage errors between the streamflows Q_{90} observed and estimated by the regionalization model for the annual period underestimated the streamflows at the Fazenda Cajupiranga, Mocidade, and Fazenda Passarão stations (Region I) and Fazenda Bandeira Branca (Region II) station, ranging from −7.24 to −32.06%.

Table 8 – Regionalization equations for the minimum streamflows Q_{90} ($m^3 s^{-1}$) considering the annual and semiannual periods (lowing and flood), as well as the observed and estimated streamflow values and the percentage error of the estimate for the streamflow gauge stations in the two homogeneous regions

(continued)

Annual Q_{90}							
Homogeneous region	Streamflow gauge station		Adjustment		Streamflow ($m^3 s^{-1}$)		PE***
			Model	R^2	Obs.*	Est.**	
Region I	14495000	Fazenda Cajupiranga	Potential	0.89	299.15	253.26	-15.34
	14500000	Mocidade			356.00	255.41	-28.26
	14515000	Fazenda Passarão			358.83	332.87	-7.24
	14680001	Fé e Esperança			80.60	103.83	28.83
	14690000	Mucajaí			134.87	142.70	5.80
	14710000	Caracaraí			564.94	735.64	30.22
	Annual $Q_{90} = 2.29x10^{-2} Ad^{0.884}$						
Region II	14530000	Vila Surumu	Potential	0.69	6.63	8.79	32.57
	14540000	Fazenda Bandeira Branca			17.00	11.55	-32.06
	14550000	Maloca do Contão			21.73	24.12	11.02
	Annual $Q_{90} = 1.07x10^{-3} Ad^{1.156}$						

Lowing Q_{90}							
Homogeneous region	Streamflow gauge station		Adjustment		Streamflow ($m^3 s^{-1}$)		PE***
			Model	R^2	Obs.*	Est.**	
Region I	14495000	*Fazenda Cajupiranga*	*Potential*	0.90	231.13	188.86	-18.29
	14500000	*Mocidade*			256.00	190.56	-25.56
	14515000	*Fazenda Passarão*			285.81	252.42	-11.68
	14680001	*Fé e Esperança*			63.80	73.32	14.93
	14690000	*Mucajaí*			82.81	102.75	24.07
	14710000	*Caracaraí*			448.54	585.56	30.55
	Lowing $Q_{90} = 9.64x10^{-3}.Ad^{0.939}$						
Region II	14530000	*Vila Surumu*	*Potential*	0.68	4.53	6.29	38.75
	14540000	*Fazenda Bandeira Branca*			13.40	8.55	-36.17
	14550000	*Maloca do Contão*			17.39	19.64	12.91
	Lowing $Q_{90} = 2.42x10^{-4} Ad^{1.304}$						

Table 8 – Regionalization equations for the minimum streamflows Q_{90} (m^3 s^{-1}) considering the annual and semiannual periods (lowing and flood), as well as the observed and estimated streamflow values and the percentage error of the estimate for the streamflow gauge stations in the two homogeneous regions

(Conclusion)

Flood Q_{90}							
Homogeneous region	*Streamflow gauge station*		*Adjustment*		*Streamflow (m^3 s^{-1})*		*PE****
			Model	*R^2*	*Obs.**	*Est.***	
Region I	14495000	*Fazenda Cajupiranga*	*Potential*	0.94	625.03	561.02	-10.24
	14500000	*Mocidade*			689.50	565.73	-17.95
	14515000	*Fazenda Passarão*			779.83	735.35	-5.70
	14680001	*Fé e Esperança*			184.40	232.09	25.86
	14690000	*Mucajaí*			333.69	317.94	-4.72
	14710000	*Caracaraí*			1342.64	1612.17	20.07
	Flood $Q_{90} = 5.56x10^{-2} Ad^{0.876}$						
Region II	14530000	*Vila Surumu*	*Potential*	0.77	15.66	19.48	24.41
	14540000	*Fazenda Bandeira Branca*			34.10	25.28	-25.88
	14550000	*Maloca do Contão*			47.04	51.01	8.44
	Flood $Q_{90} = 3.62x10^{-3} Ad^{1.102}$						

*Observed Q_{90} values; **Values estimated by the regionalization model; ***Percentage error

Source: Authors’ elaboration

The model for estimating the annual Q_{90} showed higher positive differences at the Caracaraí and Fé Esperança stations, overestimating the streamflows, which were equal to 28.83 and 30.22%, respectively. The potential model for the adjusted annual Q_{90} also overestimated the streamflows at the Mucajaí, Vila Surumu, and Maloca do Contão stations.

In general, the lowest errors in estimating Q_{90} by the regionalization equations were observed during the flood period, as they ranged from −17.95 to 25.86% in Region I and −25.88 to 24.41% in Region II.

Therefore, the errors in estimating the minimum streamflows for some stations reached up to 30% among the observed values and those estimated by the regionalization models. This considerable difference is partially due to the small number of stations in the basin, with sufficient data for a better model adjustment and, consequently, the estimation of streamflows.

4 CONCLUSIONS

The estimate and regionalize the annual and semiannual minimum reference streamflows $Q_{7,10}$, Q_{95}, and Q_{90} for the Branco River basin, presented satisfactory and consistent results to support the management of water resourses.

The hydrological year in the Branco River basin begins in May, with the increase in minimum streamflows, and extends until April of the following year.

The flooding semester of the Branco River basin covers the months from May to October, while the lowing semester covers the months from November to April.

Considering the coverage of the basin and the existence of only 13 streamflow gauge stations in the region, there is a lack of daily streamflow information that adequately subsidizes the water resources management process.

The flexibility of the granting criteria adopting seasonality in water availability allows considerable increases in the grantable streamflow in the flooding semester for the various users of the Branco River basin.

ACKNOWLEDGMENTS

To the State University of Amazonas (UEA), Fundação de Amparo à Pesquisa do Estado do Amazonas (FAPEAM), Companhia de Pesquisa de Recursos Minerais (CPRM), and National Water Agency And Basic Sanitation of Brazil (ANA).

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Authorship contributions

1 - Thiago Barboza Ribeiro

Master in Water Resources Management and Regulation

http://orcid.org/0000-0003-4513-7492 • thiago.exodo3@gmail.com

Contribution: Conceptualization; Formal Analysis; Investigation; Methodology; Writing – original draft; Visualization

2 - Luana Lisboa

PhD in Agricultural Engineering

https://orcid.org/0000-0002-7902-6072 • luana.lisboa@cprm.gov.br

Contribution: Formal Analysis; Methodology; Writing – original draft; Supervision

3 - Carlossandro Carvalho de Albuquerque

PhD in Geography

http://orcid.org/0000-0001-8399-6170 • carlosandro.albuquerque@gmail.com

Contribution: Supervision; Writing – review & editing

4 - Michel Castro Moreira

PhD in Agricultural Engineering

https://orcid.org/0000-0001-8024-7705 • michelcm@ufv.br

Contribution: Writing – review & editing

5 - Eduardo Morgan Uliana

PhD in Agricultural Engineering

https://orcid.org/0000-0003-2107-4634 • https://orcid.org/0000-0003-2107-4634

Contribution: Writing – review & editing

How to quote this article

RIBEIRO, T. B.; LISBOA, L.; ALBUQUERQUE, C. C.; MOREIRA, M. C.; ULIANA, E. M.. Estimation and regionalization of minimum reference streamflows in the Branco river basin, Roraima, Brazil, as a support for water resources management. **Ciência e Natura**, Santa Maria, v. 45, e20, 2023. DOI 10.5902/2179460X65901. available in: https://doi.org/10.5902/2179460X65901