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Assessment of the Demarcation Method for Federal Riverine and Accreted Lands: Case Study of the Rio De Janeiro State Section of the South Paraíba River

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Abstract

This study analyzes the demarcation method of riverine and accreted land of the Brazilian Federal Heritage Department and proposes the incorporation of the flow rate corresponding to the recurrence interval of two years, as recommended by the State Environmental Institute of the state of Rio de Janeiro. The case study of the Rio de Janeiro section of the Paraiba do Sul River was investigated, and the results indicate that the Federal Heritage Department's method does not consider the ongoing anthropization of the river, caused mainly by the construction and operation of hydroelectric plants. In addition, it was observed that the limnimetric scales of the studied gauging stations are influenced by constant changes in the riverbed and by riverbank occupation, making it difficult to estimate the ordinary flood level. The study concludes by suggesting the adoption of a flow rate with a recurrence interval of two years and the simulation of the runoff conditions for demarcation of the average ordinary flood line.

Keywords

Federal Heritage Department, Limnimetric Scales, Average Ordinary Flood Level

1. Introduction

To support land use and environmental planning, government planning and especially continuous monitoring are essential. When there is no such supervisory action, population occupation and expansion can occur in areas belonging to the federal government or in areas that should be preserved, thus impairing the social and environmental balance [1].

The Brazilian Federal Heritage Department (Secretaria de Patrimônio da União—SPU), an agency under the Ministry of Planning, Development and Management, is responsible for managing federal government assets. Its responsibilities include incorporating and regulating the government's assets, including riverine lands of federal navigable rivers. To regulate these riverine lands, demarcation of the mean ordinary flood line (MOFL) is required, and when that is not possible, it is necessary to consult documents that indicate the position of the riverbanks in 1867 or close to it [2].

The SPU's method can be difficult to implement, such as when it refers to the cartographic representation of the year 1867. According to [3], the federal government has found it difficult to carry out this demarcation in strict observance of the law, and because of that, many decisions by the Superior Court of Justice (STJ) have nullified the demarcation process precisely due to the lack of scientific and technical criteria.

This lack of standardization is also cited by the Brazilian Court of Auditors (Tribunal de Contas da União) when it mentions that the legislation governing the demarcation is too broad and lacks regulation, which leads to interpretation uncertainties by the operating agencies/entities and cites as an example the divergence in understanding between the National Water Agency (Agência Nacional de Águas—ANA) and the SPU regarding federal rivers and their respective riverine lands. According to the TCU, the absence of standards addressing conceptual aspects (such as the MOFL, navigation, floatage and riverbeds) hinders the action of the SPU in the performance of its duties, specifically in real estate evaluations for which physical and geographical boundaries require objective regulatory benchmarks [4].

Based on the above, the present study investigates the MOFL demarcation method and compares it with the method recommended by the State Environmental Institute (Instituto Estadual do Ambiente—INEA) in the demarcation of the riverbank protection zone (RPZ).

As a case study, the stretch of the Paraiba do Sul River running through the state of Rio de Janeiro was chosen. The Paraiba do Sul River is a federal waterway that crosses and serves as a boundary of the states of São Paulo, Rio de Janeiro and Minas Gerais. The Rio de Janeiro section was selected because of the constant changes made to the riverbed and banks due mainly to riverside occupation and the operation of existing hydroelectric plants.

2. Conceptualization of Hydraulic and Hydrological Parameters

2.1. Regular River Channel and Minor Riverbed

According to Law 12,651/2012, a regular riverbed corresponds to a channel where water runs regularly throughout the year, and a floodplain corresponds to areas marginal to the watercourses that are subject to periodic flooding (Sections XIX and XXI of Art. 3) [5].

The term regular channel is associated with a flow that fills the cross channel of the river up to the maximum level before overflow, called the dominant flow [6]. The author adopted the flow associated with the return period or recurrence interval (RI) of 2 years to calculate the reference width of the regular channel.

According to [7], the flood elevation for the minor riverbed is usually found at an RI of between 1.5 and 2 years.

According to SPU, the major seasonal riverbed is the widened or largest channel of a river, occupied during annual flood periods. The minor riverbed is defined as the part of the channel occupied by waters with a frequency that prevents the growth of vegetation. This type of riverbed is bounded by well-defined margins [2].

2.2. Ordinary Floods

According to [8], a flood can be classified as ordinary or extraordinary, with the first type referring to floods with a magnitude corresponding to the average annual flood flow, and the second type referring to floods with a magnitude greater than the average annual flood flow.

Reference [9] mathematically demonstrated that the average annual flow has an RI of 2.33 years. A similar RI value of 2.3 was also found by [10] for North American rivers.

To estimate the maximum flow associated with a given RI, it is necessary to adjust the flow data with a probability distribution to obtain a relationship between the random variable (maximum flow) and the probability of an event in which that flow is matched or exceeded. Regarding the distribution functions, this study adopted the Gumbel distribution or the two-parameter exponential distribution, according to the skewness of the sample, as recommended by [11]. If exceeding 1.5, the two-parameter exponential distribution is adopted; otherwise, the Gumbel distribution is adopted.

The design quantile of the two-parameter exponential distribution is expressed by:

$$X_T = X_0 - \beta \cdot \ln\left(\frac{1}{\mathrm{RI}}\right) \tag{1}$$

$$X_0 = \bar{X} - s \tag{2}$$

$$\beta = s \tag{3}$$

where X_T is the design quantile, that is, the maximum flow for a given RI; X_0 and β are the distribution parameters; s is the sample standard deviation; $\bar{X}$ is the sample mean; and RI is the return period or recurrence interval in years.

The design quantile of the Gumbel distribution is expressed as

$$X_T = \mu - \alpha \cdot \left(\ln \cdot - \ln\left(1 - \frac{1}{\mathrm{RI}}\right)\right) \tag{4}$$

$$\alpha = 0.78 \cdot s \tag{5}$$

$$\mu = \overline{X} - 0.577 \cdot \alpha \tag{6}$$

where α and μ are the parameters of the distribution.

The mean, standard deviation and skewness of the sample are estimated as follows:

$$\overline{X} = \frac{1}{n} \cdot \sum_{i=1}^{n} X_i \tag{7}$$

$$s = \left[\frac{1}{n-1} \cdot \sum_{i=1}^{n} \left(X_i - \overline{X} \right)^2 \right]^{0.5} \tag{8}$$

$$g = \frac{n}{(n-1)\cdot(n-2)} \cdot \left(\frac{\sum_{i=1}^{n} \left(X_i - \overline{X} \right)^3}{S^3} \right) \tag{9}$$

where n is the sample size.

3. Materials and Methods

3.1. Delimitation of the Study Area

The Paraíba do Sul River basin represents 0.7% of Brazil's area and approximately 6% of the Southeast Region. The area occupied by the basin corresponds to 63% of the total area of Rio de Janeiro, 5% of São Paulo and 4% of Minas Gerais, as shown in Figure 1 [12]. As its waters drain more than one state, the river

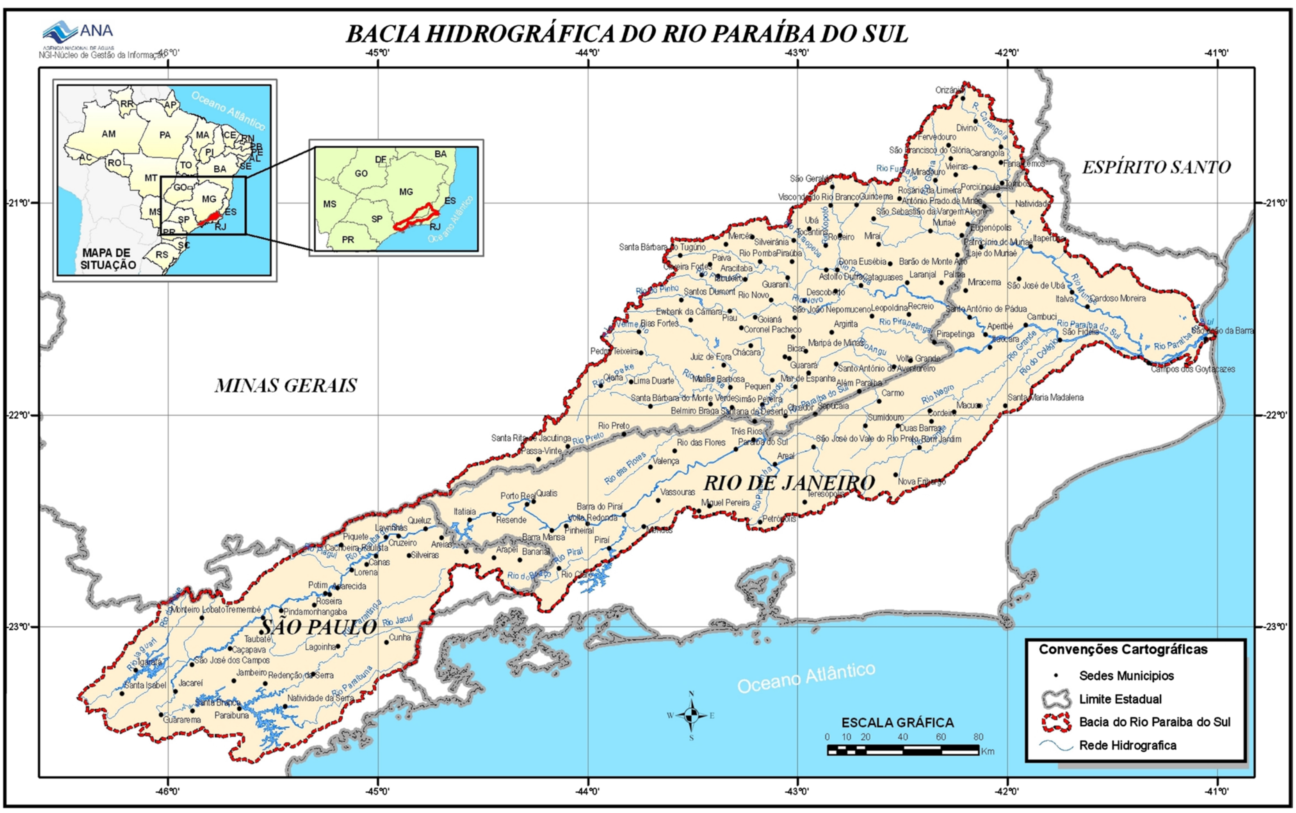

Figure 1. Map of the Paraíba do Sul River Basin [14].

is classified as belonging to the federal government, and its management, in accordance with Art. 4 of Law 9984/2000, is the responsibility of the ANA [13].

Hydropower plants (HPP) were built along the Paraíba do Sul River, mainly between the 1920s and 1970s, in locations such as Paraibuna/Paraitinga, Santa Branca, Funil and Ilha dos Pombos. The Paraíba do Sul/Guandu river system is also noteworthy because the transposition of the Paraíba do Sul River waters in Santa Cecilia supplies the Greater Rio de Janeiro Region and provides its electricity. Anta and Simplício were the last set of HPPs built in the 2010s [12].

Figure 2 shows the longitudinal profile of the Paraíba do Sul River with the respective elevations of the cities and HPPs. It can be observed that the Rio de Janeiro section starts from the Funil HPP, with its mouth in the city of Campos dos Goytacazes.

The Funil HPP was built in the middle section of the Paraíba do Sul River, in the state of Rio de Janeiro, and began operating in November 1969. The dam is a double-curved, dome-shaped concrete structure. Its reservoir can accumulate nearly 900 million cubic meters of water. The project has great importance for the regulation of flow rates, helping to reduce the frequency and intensity of floods that occur in the cities of Resende, Barra Mansa, Volta Redonda and Barra do Pirai [12].

In the city of Barra do Pirai, the waters of the Paraíba do Sul River are transposed through the Santa Cecilia reversible hydropower plant (RHPP) to the Ribeirão das Lajes River Basin. Downstream, the waters of the Paraíba do Sul River

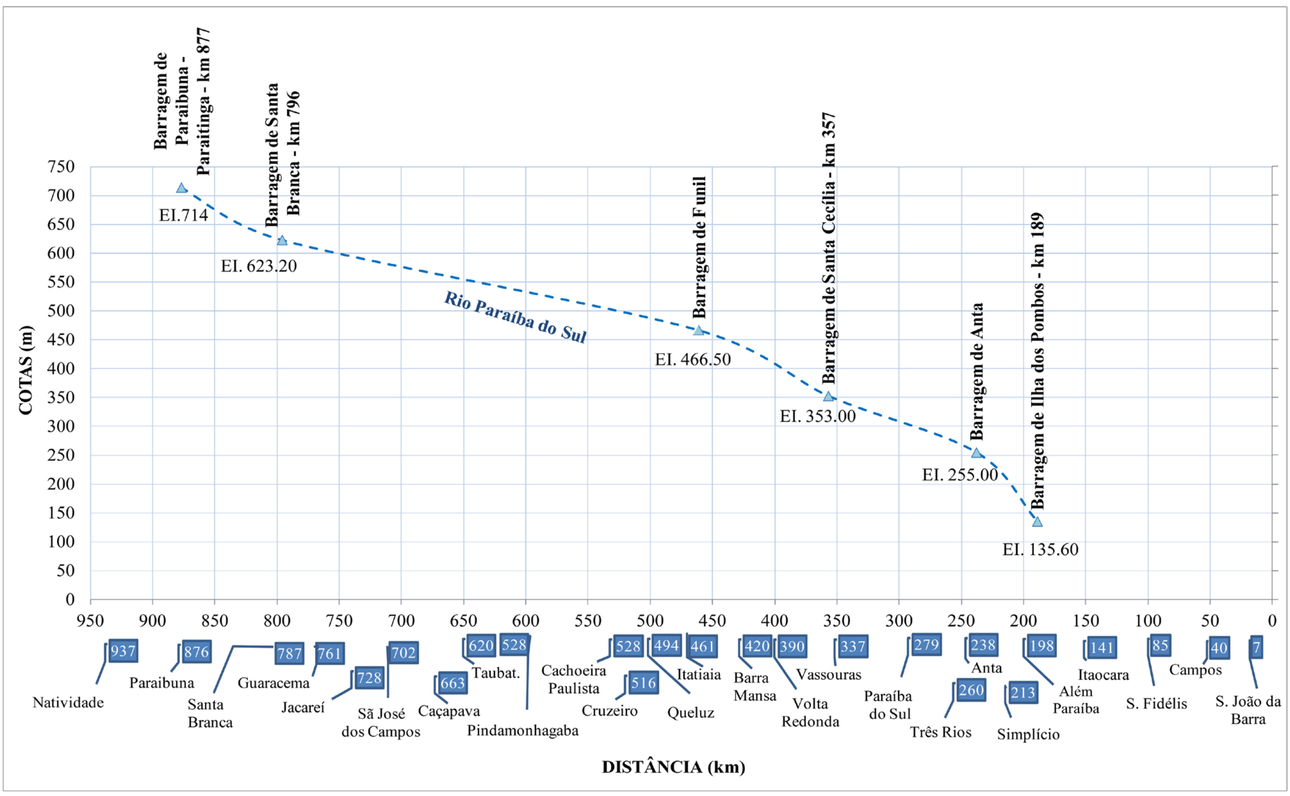

Figure 2. Longitudinal profile of the Paraíba do Sul River [15].

run with the reduced flow to meet the waters of the Paraibuna River then flex toward its delta before emptying into the Atlantic Ocean in São João da Barra [16] [17]. Under normal operating conditions, the deflection can transpose a flow rate equal to 160 m^3/s, which corresponds to approximately 54% of the natural river flow, keeping the downstream discharge of the Santa Cecilia RHPP at 90 m^3/s [18].

The Simplicio HPP was built by Furnas and is located on the border between the states of Rio de Janeiro and Minas Gerais, covering the municipalities of Três Rios and Sapucaia in Rio de Janeiro and the mining towns of Chiador and Além Paraíba in Minas Gerais [19]. The arrangement includes the Paraíba do Sul River Dam, where the Anta HPP is located, upstream of the Anta district, and its 30-km-long diversion to the Simplício HPP, located near the town of Além Paraíba. The complex went into operation in June 2013 [20].

The last plant of the Rio de Janeiro stretch of the Paraíba do Sul River is the Ilha dos Pombos HPP, located between the cities of Carmo and Além Paraíba. The plant was built in the 1920s and began operating in 1924 [21].

3.2. Demarcation of Riverine and Accreted Land

The responsibility to demarcate riverine lands (bathed by rivers, lakes or any federal water bodies out of reach of the tides), marine lands (when there is tidal influence) and accreted lands owned by the federal government is attributed to the SPU, through administrative and declaratory procedures defined in Decree-Law No. 9760/1946 [22]. According to the decree, the SPU must complete the identification/demarcation of such lands until December 31, 2025.

To be able to demarcate these riverine lands, it is necessary to previously determine the MOFL, from which 15 m shall be counted towards the land, in addition to the incorporation or removal of lands that occurred naturally or artificially until 1867 [2].

To determine whether the change was before 1867, the method recommends that a document search be made, giving preference to documents that come closest to that date.

As for the definition of the MOFL, the method proposes that research on the existence of gauging stations be conducted and all available information be included. When the data are insufficient or unavailable, the flood levels may be determined by limnimetric scales, which should be installed on observation stations and distributed according to the slope of the water surface elevation.

For the stretches where there are gauging stations, the calculation of the mean ordinary floods uses only the data from the scale readings of stations with at least 20 years of observations and for which the maximum annual elevation values have been obtained. These elevations should be arranged in decreasing order, disregarding floods with an RI of less than 3 years and floods with an RI equal to or greater than 20 years. With the resulting values, the arithmetic mean is calculated, which is the average elevation of an ordinary flood. To be able to determine the elevation of an ordinary flood, the scale readings must be referenced to the official Brazilian vertical datum.

For cases in which there are no changes in the riverbanks, such as landfills or silting, either natural or artificial, the elevation defines the MOFL position; otherwise, the MOFL is defined according to studies and document research. If these accreted lands (natural or artificial embankments) or eroded lands (fluvial erosion advances) originated before 1867, they will be considered in the range of riverine lands and will be added to or subtracted from the range of 15 m from the MOFL; otherwise, they will not be considered.

3.3. Demarcation of the Riverine Protection Zone

State law No. 650 of January 11, 1983 establishes the state policy of defending and protecting river and lake basins in the state of Rio de Janeiro and sets standards of protection, conservation and monitoring of state watercourses and their riverine lands (arts. 1 and 2); further, one of the control instruments of this law is the RPZ [23]. RPZs are to be demarcated by the State Superintendent of Rivers and Lakes (SERLA) for all water bodies in the state of Rio de Janeiro [24].

It should be noted that the duties of the SERLA were transferred to the State Environmental Institute (INEA), which, in turn, published the Operating Standard (NOP) No. 33 for RPZ demarcation on January 8, 2016 [25]. The document establishes the criteria and procedures to be adopted for demarcation and is valid for water bodies that are fully or partially included in the state of Rio de Janeiro. The RPZs of the portions of the federal waterways that are included in the state's territory are also demarcated.

NOP-INEA Paragraph 33 states that the minimum RPZ width is demarcated from the river section defined by the passage of a certain flood associated with an RI. For non-consolidated urban areas, the flow rate to be used shall correspond to an RI of 2 years, which represents the section of the regular channel, and the width of the RPZ should respect the values established by the Forest Code. For consolidated urban areas, the flow rate to be adopted corresponds to an RI of 10 years, from which a 15 m range is marked.

Based on the reference flow value (an RI of 2 years or 10 years) and topo-bathymetric surveys of river cross-sections, the width of an RPZ must be estimated by computational modeling of river hydraulics.

When a topo-bathymetric survey is not available, for areas classified as non-urban consolidated areas, the width is estimated using the regional curves that result from the relationship of the width of the watercourse cross-section versus the maximum flow with an RI of 2 years, as shown in **Table 1**. For consolidated urban areas, it is recommended that the hydraulic simulation be based on a theoretical section measured in an on-site survey.

3.4. Data Survey and Analysis

Historical series of water level, flows and discharge summaries from the gauging stations were obtained from the ANA Hidroweb system. Then, for each station, the gap periods of the available time series were evaluated.

With regard to the historical data, we attempted to analyze the influence of the presence of hydropower developments on the flow rates and water surface levels along the Rio de Janeiro stretch of the Paraíba do Sul River because according to MMA (2006), from the viewpoint of hydraulic dynamics, the installation and operation of HPPs demand the continuous control of reservoir operations to ensure that the necessary restrictions are being met and possible downstream and upstream interferences are being considered.

The Funil HPP, which began operating at the end of 1969, is the plant with the largest regulated reservoir, and it controls the flooding of the Rio de Janeiro stretch of the Paraíba do Sul River. To analyze the influence of this development on the historical series, two periods were considered: before 1970 and since 1970. The SPU and INEA methods were applied for each of these periods.

The selected gauging stations are listed in Table 2.

Table 1. Equations to determine the reference width [25].

Coastal Basins	3.7425 (QRI20.4757)
Paraíba do Sul River Basin	1.8543 (QRI20.6495)
Piabanha River Basin	2.1163 (QRI20.5503)
Dois Rios River Basin	2.2010 (QTR20.588)

Table 2. Selected gauging station

Code	Name	Latitude	Longitude	Drainage Area (km^2)
58242000	Funil HPP Downstream 1	22˚30'1.08"	44˚33'15.12"	13,400
58250000	Resende	22˚28'0.12"	44˚26'43.08"	14,000
58300000	Funil HPP Downstream 2	22˚32'15.00"	44˚10'32.88"	15,800
58305001	Volta Redonda	22˚30'6.84"	44˚5'27.96"	16,000
58321000	Barra do Piraí*	22˚27'2.16"	43˚47'52.08"	17,639**
58370000	Santa Cecilia Barra do Pirai RHPP	22˚27'0.00"	43˚47'49.92"	19,800
58380001	Paraíba do Sul***	22˚9'46.08"	43˚17'11.04"	21,400
58385000	Ilha dos Pombos Três Rios HPP	22˚7'10.92"	43˚12'27.00"	21,600
58630002	Anta	22˚2'7.08"	42˚59'26.88"	32,700
58652000	Ilha dos Pombos HPP Dam	21˚51'9.00"	42˚36'23.04"	34,300
58795000	Três Irmãos	21˚37'32.88"	41˚59'7.08"	45,300
58880001	São Fidelis	21˚38'43.08"	41˚45'7.92"	48,900
58974000	Campos Municipal Bridge	21˚45'11.88"	41˚18'1.08"	55,700
58242000	Funil HPP Downstream 1	22˚30'1.08"	44˚33'15.12"	13,400

*Station located upstream of the Santa Cecilia RHPP. **Extracted from [12]. ***Station located downstream of the Santa Cecilia RHPP.

4. Results and Discussion

To compare the two methods, we assumed that the minor riverbed and regular channel parameters were synonymous and based on a flow with an RI of 2 years, which is synonymous with an ordinary flood.

In addition, it was observed that the water level data obtained from Hidroweb do not refer to elevations but to the scale readings. It is worth noting that the limnimetric scales are intended to follow the variation of the river water levels, and as pointed out in [26], to convert a scale reading to an elevation, the scales must be anchored and geometrically leveled in reference to the Brazilian Geodetic system. It should be noted that in the selected gauging stations, we did not observe the anchoring of the scales to a datum with the Brazilian Geodetic System reference level, which prevents the conversion of the scale readings into elevations.

As mentioned, for each gauging station, we evaluated the gap periods of the available scale readings and flow series, which are listed in **Table 3**.

Table 3 shows that three gauging stations (Santa Cecilia RHPP Barra do Pirai, Ilha dos Pombos HPP Três Rios and Ilha dos Pombos HPP Dam) were omitted because they have a data series of less than 20 years, which is the minimum size required by the SPU. In three other stations, the method cannot be applied for the period before 1970 because the series have less than 20 years of data. These stations include Funil HPP Downstream 1 (11 years of observations), Paraíba do

Table 3. Gap period for elevation and flow data.

Code	Observation Period of Scale Readings	Gap Period of Scale Readings	Flow Observation Period	Flow Gap Period
58242000	1957 to 2016	1965 to 1967; 2007	1957 to 2016	1965 to 1978; 2002 to 2007
58250000	1930 to 2016	1949 to 1952; 1965 to 1967; 1969; 1980 to 1982; 1996 to 1998; 2008 to 2010	1930 to 2016	1949 to 1952; 1965 to 1967; 1969; 1980 to 1982; 1996 to 1998; 2008 to 2010
58300000	1932 to 2016	1937 to 1940; 1949 to 1952; 1965 to 1967; 1980 to 1988; 2008 to 2010	1941 to 2016	1949 to 1952; 1965 to 1967; 1979 to 1989; 2008 to 2010
58305001	1941 to 2014	1949 to 1952; 1965 to 1967; 1970; 1979 to 1988	1941 to 2014	1949 to 1952; 1965 to 1967; 1970; 1979 to 1988
58321000	1922 to 1995	No gap	1922 to 1994	1949 to 1952; 1965 to 1967; 1970 to 1975
58370000	1998 to 2012	2002 to 2004; 2011; 2012	No data	No data
58380001	1956 to 2014	1972; 2006; 2013	1973 to 2014	2006; 2013
58385000	1998 to 2012	2000; 2002 to 2011	1998 to 2012	2000; 2002 to 2011
58630002	1923 to 2014	No gap	1923 to 2014	No gap
58652000	1998 to 2012	2007 to 2012	No data	No data
58795000	1931 to 2014	1949 to 1952; 1965 to 1967	1931 to 2014	1949 to 1952; 1965 to 1967
58880001	1925 to 2014	1944 to 1970; 1972; 2008	1973 to 2014	2008
58974000	1923 to 2014	1949 to 1952; 1965 to 1967	1923 to 2014	1949 to 1952; 1965 to 1967
58242000	1957 to 2016	1965 to 1967; 2007	1957 to 2016	1965 to 1978; 2002 to 2007

Sul (15 years of observations) and São Fidélis (19 years of observations). The results obtained using the SPU method are listed in **Table 4**.

For analysis of the SPU method, it was necessary to estimate the flow and RI for each scale reading based on the use of the rating curve (s) of each gauging station in each of the periods. The results are listed in **Table 5**.

Table 5 shows that the greatest scale reading does not always correspond to the greatest flow rate. For the Resende, Barra do Piraí, Anta and Três Irmãos stations, the scale reading values until 1970 are lower when compared to the period since 1970; however, their corresponding flow rates are higher. In the Campos Municipal Bridge station, the opposite is observed. These results can be explained

Table 4. Scale readings calculated based on the SPU method.

Gauging Station	Scale Reading (m)	
	Period before 1970	Period Beginning in 1970
Funil HPP Downstream 1	Period < 20 years	4.50
Resende	3.12	3.95
Funil HPP Downstream 2	4.39	4.53
Volta Redonda	5.08	5.06
Barra do Piraí	4.46	4.48
Paraíba do Sul	Period < 20 years	4.56
Anta	5.49	5.99
Três Irmãos	4.85	5.37
São Fidélis	Period < 20 years	5.72

Table 5. SPU method: flow rate and RI associated with the scale readings.

Station	Before 1970			Since 1970		
	SR (m)	Flow Rate (m^3/s)	RI (Years)	SR (m)	Flow Rate (m^3/s)	RI (Years)
Funil HPP Downstream 1	Period < 20 years			4.50	700	7.3
Resende	3.12	990	3.1	3.95	597	2.5
Funil HPP Downstream 2*	4.39	-	-	4.53	972	6.3
Volta Redonda	5.08	1157	6.8	5.06	1042	6.0
Barra do Piraí	4.46	1328	5.3	4.48	1233	7.4
Paraíba do Sul	Period < 20 years			4.56	903	7.5
Anta	5.49	2275	5.8	5.99	2021	6.5
Três Irmãos	4.85	3453	9.2	5.37	3181	6.5
São Fidélis	Period < 20 years			5.72	4311	7.3
Campos Municipal Bridge	10.68	4528	6.5	10.64	4605	7.0

SR—scale reading. *The station only has a rating curve from 1988, but it has scale readings since 1932.

by the definition of several rating curves for each station in different periods. For the RI, it is noted that there is a convergence to a common value because there was a fluctuation between 2.5 and 9.2 years.

A comparison of the percentage difference between the flow rates of the two periods is shown in **Table 6**.

Table 6 shows that the period up to 1970 had larger flow rates than the period since 1970, except for the Campos Municipal Bridge station, located near the mouth of the river. The Resende station had the highest percentage difference, which can be explained by its location immediately beyond the Funil HPP reservoir, with its flood control ability. The Campos result can be explained by the considerable distance from the Funil HPP to the mouth of the river, where the flood control effects are not as strong as they are at the Resende station.

With regards to the application of the INEA method for each gauging station, in every specified period, the flow rate was calculated with an RI of 2 years. The results are shown in **Table 7**.

According to **Table 7**, in all the gauging stations, the flow rates before 1970 are higher than the flow rates since 1970. Under the INEA methodology, the Resende station also presented the highest percentage variation in flow rate between the periods.

The overall analysis of the results indicates that, for both methods, the period before 1970 had the highest flow rates. This result is explained by the operation of the Funil HPP in controlling floods in the downstream section and the water transposition in Santa Cecilia. This influence was also highlighted by [27] in a study that compared the daily natural flow series provided by the National Power System Operator (Operador Nacional do Sistema Elétrico—ONS) with a series of daily maximum flow rates obtained in gauging stations located along the Paraíba do Sul River. The study by [28] is also noteworthy, as it found a negative trend in historical series of flows due to anthropogenic regulatory action and intensive water usage.

Table 6. Percentage variation in the flow rates before 1970 and since 1970

Station	Percentage Variation in the Flow Rate between the Periods
Funil HPP Downstream 1	-
Resende	39.67
Funil HPP Downstream 2	-
Volta Redonda	9.91
Barra do Piraí	7.11
Paraíba do Sul	-
Anta	11.17
Três Irmãos	7.87
São Fidélis	-
Campos Municipal Bridge	-1.70

Table 7. Flow rate with an RI of 2 years and the percentage change in the flow rate between the periods up to 1970 and since 1970

Station	Flow Rate for RI of 2 Years (m^3/s)		Percentage Variation in Flow Rate between the Periods (%)
	Before 1970	Since 1970	
Funil HPP Downstream 1	Period < 20 years	500	-
Resende	860	553	35.69
Funil HPP Downstream 2	775	726	6.34
Volta Redonda	838	754	10.01
Barra do Piraí*	975	772	20.82
Paraíba do Sul**	No data	646	-
Anta	1758	1531	12.91
Três Irmãos	2360	2215	6.14
São Fidélis	No data	2727	-
Campos Municipal Bridge	3360	3026	9.95

*Station located upstream of the Santa Cecilia RHPP. **Station located downstream of the Santa Cecilia RHPP. The flow decreases, because the transposition of the Paraíba do Sul River waters in Santa Cecilia

5. Final Considerations

The cross-sections of the gauging stations installed along the Rio de Janeiro section of the Paraíba do Sul River have undergone continuous modifications from anthropogenic activities, including riverside population occupation, sand extraction, the construction of bridges and hydropower developments, flood control and transpositions/derivations. This ongoing process is reflected by the establishment of numerous rating curves for each of the stations, which greatly hinders the collection of an extensive range of scale readings and flow rate data.

Regarding the scale readings, we stress the importance of anchoring and geometrically leveling the scales in reference to the Brazilian Geodetic System for the correct application of the SPU methodology. Under current conditions, the defined criteria are not met in the Rio de Janeiro section of the Paraíba do Sul River.

Furthermore, the flood flow regime of the Rio de Janeiro section underwent a significant reduction after the implementation of the Funil HPP, which controls and reduces the frequency and magnitude of floods for the downstream stretch with its considerable waiting volume. Therefore, it can be inferred that the SPU method is not the most suitable one for this section given the significant changes in the hydraulic/hydrology system of the river channel since 1970. Furthermore, these changes took place over 100 years after the requirement for referencing cartographic representations to the year 1867.

It is suggested that the SPU adopt a characteristic flow representative of ordinary floods to allow assessment of the runoff and cross-sections at each gauging station or site of interest. In the case of the Paraíba do Sul River, this flow may be equivalent to that adopted by INEA when demarcating RPZs, that is, an RI of 2 years.

It is believed that the demarcation of the MOFL along a river should not be evaluated individually at each gauging station or site of interest because the river has its own dynamic flow. Thus, future studies should model the hydrodynamic runoff conditions of the Rio de Janeiro section of the Paraíba do Sul River to establish the water levels corresponding to floods with an RI of 2 years and then confirm these levels on site through topo-bathymetric surveys.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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