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REFERENCE FLOW FOR GRANTING RIGHTS TO USE WATER RESOURCES IN NEGRO RIVER

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Abstract: Themes related to water resources can be analyzed from different perspectives, among these are the studies that prove that this element has come to be endowed with economic value due to the various uses for human purposes, since this natural asset is non-renewable and has availability finite. One of the ways to verify the water availability among users is through the analysis of the reference flow in a given body of water. Thus, the purpose of this article is to gather data on minimum and maximum flows and reference flow of the Negro River sub-basin from the Serrinha Fluviometric Station, in periods of floods and ebbs of the river. The records used started from a 30-year interval, over the years 1978 to 2019, in which they were used for the composition of the hydrogamma of maximum and minimum flows and elaboration of the permanence curve. Under this parameter, the flow values vary between 28.124,52 m^3/s in june and 11.444,56 m^3/s, in February. Based on the permanence curve, which is an important resource for granting purposes, it has been shown that the water availability of the Negro River in 95% of the time is maintained at the flow of 7.266,01 m^3/s. Based on the results obtained, it is inferred that this sub-basin has great potential for water availability.

Keywords: Grant of Use, Water Resource, Flow.

INTRODUCTION

The existing relationship between water and the construction process of the Amazonian population occurred in an interconnected way and this is identified when one observes that these peoples developed on the banks of important water bodies, such as the Negro River and its respective tributaries. In the current scope, several installations are identified, whether commercial or housing, in the beds and edges of the rivers, which reiterates the theory of the daily dynamics between the Amazonian man and the uses of water. However, the constant use of water to meet human needs, linked to population growth, has triggered visible environmental problems, such as land use and occupation, contamination of surface sources, as well as underground water bodies. Nelson (2017) states that due to these occurrences, the use of water came to be viewed as a finite, non-renewable and limited natural resource, with economic value.

Due to the great importance of water resources for maintaining the lives of the existing populations in Amazonas, the State Water Resources Plan (PERH/AM) is being prepared, which will deal with the establishment of criteria for the use of water in the state, based on the guidelines set out in the Law Federal Nº 9.433/97, popularly known as the Water Law, which establishes the National Water Resources Policy and which provides as one of its 06 (six) management instruments the granting of water use rights (Brasil, 1997).

The National Agency for Water and Basic Sanitation (ANA) states that the grant is a requirement that occurs for those who use or intend to benefit from water resources, whether for abstraction of surface or underground water, or for the release of effluents, or for any action that interferes with the existing water regime, in addition to the use of hydroelectric potential. In view of the frequent changes in river courses, there was a need to establish mathematical and statistical studies that verify the information from the Fluviometric Stations.

Once collected, the data generates hydrographs, in which the product is a graph with the average daily flows over all years, in order to present the limits of flows throughout the historical series. Also, it allows the generation of the maximum and minimum curve graph, which inserts the data obtained in a temporal graph, the values of the maximum and minimum annual flows during the entire period in which the river began to be measured and the permanence curve.

Based on the above, this study seeks to generate the Negro River permanence curve, as well as the hydrograph and maximum and minimum curve, using data obtained from the National Agency for Water and Basic Sanitation (ANA) database, Hidroweb Portal, in order to analyze the behavior of the river over the years and establish a reference flow. This way, subsidize the proper management of water resources in the state of Amazonas.

MATERIAL AND METHODS

STUDY AREA

The present study deals with the watercourse called Negro River, located in its largest portion in the northern region of Brazil. According to Zeidemann (2001), from its source (pre-Andean Colombia, where it rises under the name Guainía river) to its mouth, the Negro River runs for about 1,700 kilometers and is responsible for approximately 15% of the water contribution received by the Atlantic Ocean. Specifically, the Negro River drains an area corresponding to 10% of the seven million square kilometers of the Amazon Basin.

As defined by the National Water Resources Council (CNRH, 2003), a hydrographic region is characterized by an area of land and sea, composed of one or more contiguous hydrographic basins and associated groundwater and coastal waters. Therefore, the hydrographic region is an administrative division, constituting itself as the main unit of water planning and management, based on the hydrographic basin. In this context, on October 15, 2003, the National Water Resources Council, through Resolution Number 32 (Published in the Federal Official Gazette on 12/17/2003), established the National Hydrographic Division, in Hydrographic Regions, with the purpose of guiding, substantiating and implementing the National Water Resources Plan (PNRH) throughout the Brazilian territory. This way, the Negro River was responsible for the formation of sub-basin 14, belonging to the Amazon Basin, called Basin 1.

Within the scope of the local region, it must be noted that the state of Amazonas holds most of the Negro River hydrographic basin (sub-basin region 14 of Brazil), in addition, in that state, the great importance of the Planning Unit is observed. (UPH) of Baixo Negro (Figure 1), responsible for about 54% of the water demand (m^3/s) of the state total (SEMA, 2019).

DATA

The choice of the station considered two main criteria: proximity to the mouth of the river to be analyzed and the amount of flow data available by the station. Thus, for the Negro River, there were around 27 stations available in the sub-basin (14). For the present analysis, the stations closest to the mouth of the water course and the number of years of available flow data were verified, opting for the most representative one for the present study (we adopted as a minimum parameter the data series of 30 years).

Thus, in Table 1, below, the fluviometric stations available and closest to the mouth of the Negro River are listed, until the verification of the representative data series to be adopted. In relation to the other stations belonging to sub-basin 14, these were discarded in view of the high distance in relation to the mouth of the water course.

After the aforementioned analysis, for the development of this work, the outflow data from the SERRINHA station, registered in the ANA database under code 14420000, obtained from the Hidroweb Portal (http://www.snirh.gov.br/hidroweb/publico/medicoes_

Figure 1 – Water Planning Units in the state of Amazonas.

Source – Authors (2021).

Fluviometric station	Code	Distance to the mouth of Negro River (km)	Available data series		
			Start	End	Total (years)
Manaus	14990004	13,5	No flow data available		
Ponta Pelada	14910900	23,2			
Paricatuba	14910000	40,3			
Manacapuru	14100000	41,8	1992	2020	28
Estação Intermediária	14900150	42,6	No flow data available		
Rio Cuieiras	14941000	70,1			
Fazenda Recreio	14235200	100,1			
Novo Airão	14900050	127,5			
Negro River	14901000	128,4			
Anamã	14050000	161,4			
Baruri	14880000	180,4			
Seringalzinho	14876000	241,5			
Moura	14840000	266,5			
Umanapana	14855000	316,9			
Santa Maria do Boiaçu	14790000	359,1			
Barcelos	14480000	416,1			
Samauma	14452000	416,8			
Vila Conceição	14428000	585,9	2000	2019	19
Posto Ajuricaba	14440000	590,2	1982	2020	38
Missão Catrimani	14750000	596,7	No flow data available		

Serrinha	14420000	629,6	1977	2020	43
Mucajaí	14690000	630,1	1995	2019	24
Açariquara	14422000	631,4			
Bacuri	14421000	657,6			
Posto Funai	14650000	830,7	No flow data available		
Curicuriari	14330000	847,2			
São Gabriel da Cachoeira	14320000	879,9			

Table 1 – Fluviometric stations available for data analysis – Sub-basin 14 (Negro River).

Source – Authors (2021).

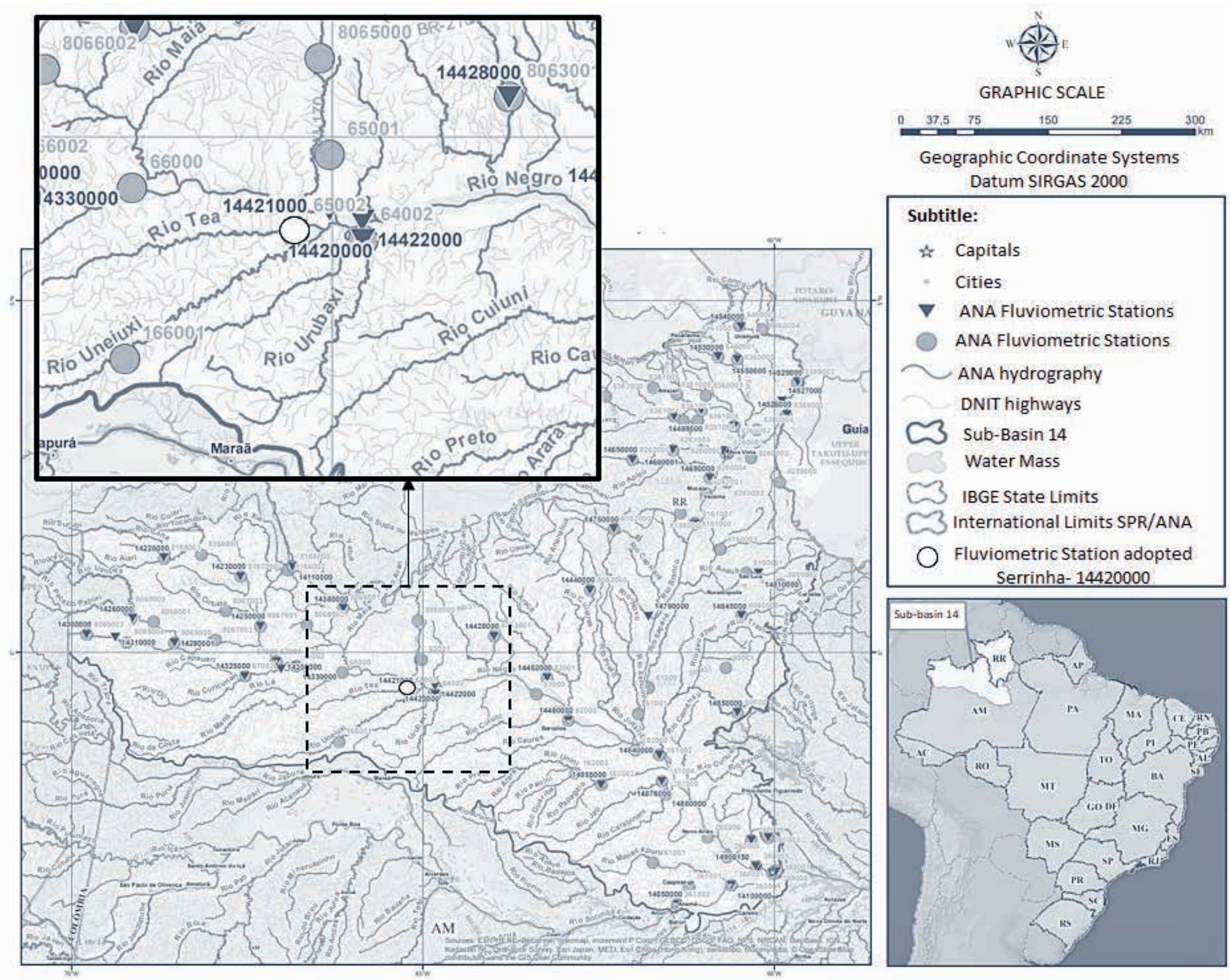

Figure 1 – Location of the fluviometric station of Serrinha – 14420000.

Source – Authors (2021).

historicas_abas.jsf), belonging to the National Information System on Water Resources (SNIRH), and which provides a range of hydrological data collected by the National Hydrometeorological Network (RHN).

The Serrinha station had a series of data started in 1977 and with the last collection obtained in January 2020, not updated for the current year, in view of the fact of force majeure of the current world scenario, caused by the Covid-19 pandemic.

Despite the series having 43 years of continuous data, the years in which failures occurred or in which incomplete data were verified were discarded, such as 2020 and 1977. Therefore, figure 2 shows the location of the fluviometric station adopted in the present study (Serrinha – 14420000).

METHODS

Based on the available flow data from the chosen station, three graphic tools were created: the permanence curve, the hydrograph and the maximum and minimum graph. For the development of these, Excel software, developed by Microsoft, was used as support in the organization of data and generation of curves.

HYDROGRAPH

This graph was obtained from sorting, in Excel, the flow data so that each column represented a year and each line of that column, a day. Therefore, a matrix of 366 lines (considering February 29 for leap years) and N_a (42) columns was formed. From each line, its average value was taken, thus representing the average flow of that day considering all the years recorded, according to equation 1.

$$q_{md} = \frac{\sum q_d}{n_{rd}} \tag{1}$$

Where:

q_{md}: average daily flow [m³/s];

q_d: daily flow [m³/s]; and

n_{rd}: number of records of the day.

The graph was prepared by placing on the abscissa axis the days equivalent to the period of a whole year, from Jan/01 to Dec/31, however, on the ordinate axis the average daily flows considering all years were distributed.

MAXIMUMS AND MINIMUMS

Using the same data organization for the hydrograph, maximum and minimum values were obtained, however, based on data for each year, separately; from these, the maximum and minimum annual values were extracted and, for the purpose of optimizing the analysis potential, the lines representing the average of each group (mean of maximums and average of minimums) were inserted, according to equations 2 and 3.

$$\bar{q}_{max} = \frac{\sum q_{max}}{n_a} \tag{2}$$

$$\bar{q}_{min} = \frac{\sum q_{min}}{n_a} \tag{3}$$

Where,

$\bar{q}_{máx}$: maximum average flow [m³/s];

$q_{máx}$: maximum annual flow [m³/s];

$\bar{q}_{min}$: minimum average flow [m³/s];

$q_{máx}$: minimum annual flow [m³/s]; and

n_a: number of years with flow records

PERMANENCE CURVE

To prepare this curve, the flows were ordered in ascending order, and each flow was assigned a discrimination corresponding to its position in the sequence, being 1 for the lowest recorded flow and n_r for the highest flow of the set. Therefore, the cumulative frequency of each flow was calculated according to equations 4 and 6.

$$f = \frac{N_o}{n_r} \tag{4}$$

$$f_{acum} = f + f_a \tag{5}$$

Finally, we set out to determine the permanence of the flows, according to equation 8.

$$P = 1 - f_{acum} \quad (6)$$

Where:

f: frequency of occurrence of flow;

n_r: number of flow records;

N_O: number of occurrences of flow;

f_a: analyzed flow frequency;

f_{acum}: cumulative frequency; and

P: flow permanence

RESULTS AND DISCUSSION

For the period of the analyzed data series (1978 to 2019), according to the hydrograph of the average daily flows, from the Serrinha station, (Figure 3), two well-defined hydrological periods are observed throughout the year, clearly denoting the seasonal characteristics of the Negro River.

According to Souza Pinto (1976), in the section of the watercourse, where the flow is being recorded, it can be seen that after the onset of precipitation, after a certain period of time has elapsed, the water level begins to rise. The flow grows from the instant corresponding to the starting point of the minimum point to the instant corresponding to the maximum point of the respective graph. This way, in the period of February, the beginning of the rise of the Hydrograph, or of the direct surface runoff, is observed, ending from the month of October, when the base flow begins, as defined by Tucci (1993).

The flood develops over several months and remains at its maximum surface for a few weeks, giving rise to an asymmetric multimodal hydrograph, with accelerated rise and slow recession, resulting from the altered equatorial regime (Rodier, 1964 and Molinier et al., 1997), with four months of floods and eight of ebbs. Floods occur between the months of March to June, when the maximum average flow is 28.124,52 m^3/s, in June. The dry period extends from July to February, when the minimum average flow is 11.444,56 m^3/s, in the month of February, presenting one or more peaks of magnitude lower than the maximum.

Figure 4 represents the amplitude of the annual maximum and minimum events, observed along the historical series studied at the Serrinha station (14420000). In the upper dispersion of dark shade, the values of maximum flows are presented and below this, the values of minimums inm^3/s per annum. The dashed lines of the upper and lower average parameters represent, respectively, the average maximum and minimum flows.

The historical maximum flow of 37.100,77 m^3/s, occurred in 2002 and the minimum among the maximum flows, of the same historical period, has the record of 24.327,15 m^3/s, in 1978. The average of the maximum flows is equivalent to 31.009,99 m^3/s. The historical minimum presented in the time series is 1.410,31 m^3/s, in 1980 and the maximum among the minimum flows is 10.596,04 m^3/s. The average of the minimum flows corresponds to 6.496,60 m^3/s. The amplitude between the maximum and minimum flow, in the historical series, of 35.690,46 m^3/s, shows how extreme the regime of floods and ebbs of the Negro River is.

According to Porto (2012) river flows are always associated with a certain probability of being equaled or exceeded or, in other words, with a permanence in time. This information is summarized in so-called permanence curves or duration curves. These curves constitute the main hydrological basis for a series of studies and decisions regarding the use and management of water resources such as, for example, energy production in a hydroelectric plant, river navigation, classification of watercourses according to their classes of

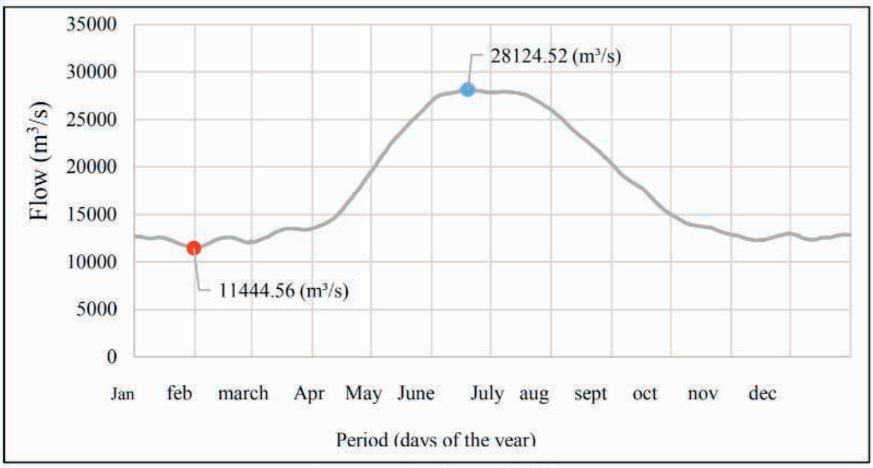

Figure 2 - Hydrogram of daily average flows of the Negro River - Fluviometric Station of Serrinha 14420000.

Source – Authors (2021).

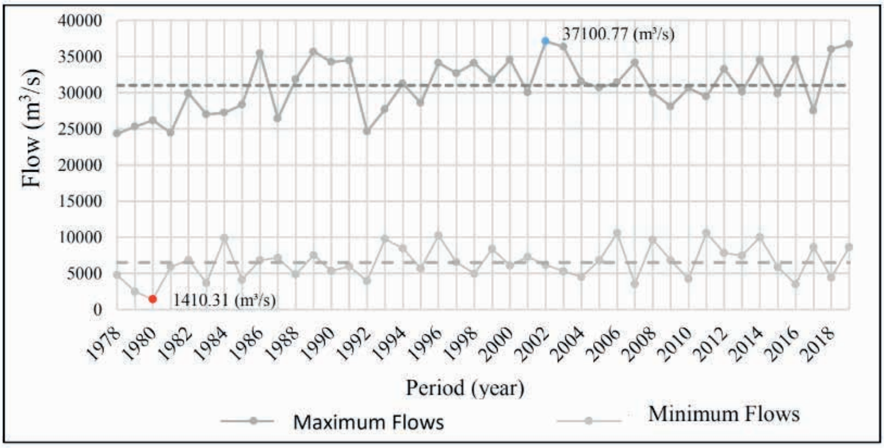

Figure 3 - Average annual maximum and minimum flows of the Negro River - Fluviometric Station of Serrinha 14420000.

Source – Authors (2021).

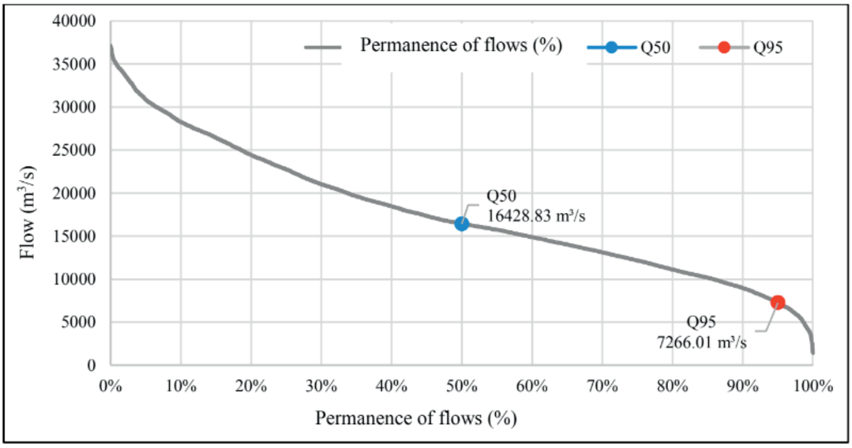

Figure 4 - Negro River Permanence Curve - Fluviometric Station of Serrinha 14420000.

Source – Authors (2021).

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use, grants of right to use water resources, environmental licensing and others. It can be seen in figure 5, the permanence curve of the Negro River, elaborated with data from the adopted fluviometric station (Serrinha – 14420000), including the complete scale from 0 to 100% of permanence of the flows observed in the period of the series of data from 1978 to 2019.

Porto (2012) also describes that Brazilian management bodies usually do not use all the information provided by the permanence curves and adopt a single flow value as the basis for their studies and decisions. This is the so-called reference flow, which in CONAMA Resolution 357 of 03/17/2005 is defined as follows:

> "Outflow of the water body used as a basis for the management process, in view of the multiple use of water and the necessary articulation of instances of the National Environmental System - SISNAMA and the National Water Resources Management System- SINGRH".

The reference flow: Q_{95} observed, corresponds to 7.266,01 m³/s. In this context, it must be noted that the State Water Resources Council of Amazonas establishes the flow rate available for the use of surface waters at 75% ofa Q_{95}, according to CERH-AM (2016); therefore, in the Negro River, the limit for flow explored is up to 5.449,51 m³/s, restrictive value. It was also verified that in 50% of the permanence period of the historical series (Q_{50}), annual flows are equal to or greater than 16.428,83 m³/s.

Porto (2012) it also points out that, whatever the flow rates adopted, there are always probabilities of failures. The risks associated with these probabilities depend on economic, environmental and social factors and are difficult to quantify. The values adopted in Brazil reflect the cautious policies of the governing bodies, which seek to prevent the degradation of our resources. In some regions, however, the general criteria implicit in the reference flows may not meet the most rational and sustainable use of the basin's resources. In this case, additional management measures must be adopted.

CONCLUSION

From the analysis of the data from the Serrinha station, over a period of 42 years, through the permanence curves, maximum and minimum curves and the histogram, it was possible to characterize the hydrological regime of the Negro River, as well as to determine the water potential the same. Through graphic analysis, it was verified that the reference flow adopted by CERH-AM for granting purposes, corresponding to 75% of the Q_{95}, is equivalent to 7.266,01 m³/s, in addition to verifying the asymmetrical behavior of the rise and fall periods of the flows of the water body studied. The highlighted flow values range from 28.124,52 m³/s in june and 11.444,56 m³/s, in February.

That said, the results achieved show the great water potential of the Negro River, thus serving as support for the management of water resources, bearing in mind that through these it is understood with greater clarity the characteristics of the hydrological regime of this important river.

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REFERENCES

AGÊNCIA NACIONAL DAS ÁGUAS E SANEAMENTO BÁSICO (ANA). (2021). *Base de Dados Hidrológicos*. Disponível em: <http://www.snirh.gov.br/hidroweb/>. Acesso em: 22 de maio de 2021;

AGÊNCIA NACIONAL DAS ÁGUAS E SANEAMENTO BÁSICO (ANA). (2016). *Metadados da Sub-bacia 14 Negro*. Disponível em:<https://metadados.snirh.gov.br/geonetwork/srv/api/records/92c8c8e2-a82e-4753-9bda- f3a6818e961e/attachments/a05._Sub-Bacia_14_Negro.pdf/>. Acesso em: 24 de Maio de 2021;

AGÊNCIA NACIONAL DE ÁGUAS E SANEAMENTO BÁSICO (ANA). (2021). *Outorga de direito de uso de recursos hídricos*. Brasília: SAG, 2011. 50 p. v.1 vol. 6. Disponível em:< https://arquivos.ana.gov.br/institucional/sge/CEDOC/Catalogo/2012/OutorgaDeDireitoDeUsoDeRecursosHidricos.pdf>. Acesso em: 27 de maio de 2021;

BRASIL (1997). Lei nº 9.433, de 8 de janeiro de 1997, que institui a Política Nacional de Recursos Hídricos, cria o Sistema Nacional de Gerenciamento de Recursos Hídricos e dá outras providências;

CONSELHO ESTADUAL DE RECURSOS HÍDRICOS DO AMAZONAS (CERH-AM). (2016). *Resolução CERH Nº 01, DE 19-07-2016*. Art. 24, V, p. 20;

CNRH (2003). *Resolução n. 32, de 15 de outubro de 2003*. Anexo I. Conselho Nacional de Recursos Hídricos. Brasília, DF: Ministério do Meio Ambiente, 2003;

NELSON, R. A. R. R. (2017). Da importância dos recursos hídricos e a organização administrativa para sua proteção. Planeta Amazônia: Revista Internacional de Direito Ambiental e Políticas Públicas. Macapá, n. 9, p. 71-88, 2017;

PINTO, N. S. et al (1976), *"Hidrologia Básica"*, Editora Edgard Blücher Ltda., São Paulo - SP, 1976;

MOLINIER, M.; GUYOT, J.L.; CALLÈDE DE, J.; GUIMARÃES, V.; OLIVEIRA, E.; FILIZOLA, N. (1997). *Hydrologie du bassin amazonien*. In: THÉRY, H. (ed.), Environnement et développement en Amazonie brésilienne, Paris, FR: Editions Belin. p. 24-41.

PORTO, R. L. L. (2012). *Fundamentos para gestão da água*. São Paulo : Secretaria do Meio Ambiente do Estado de São Paulo. 232 p.

RODIER, J. (1964) *Régimes hydrologique de l'Afrique noire à l'Ouest du Congo*. Mémoires OSTOM6, OSROM, Paris. 163 p.

SEMA (2019). *Plano Estadual de Recurso Hídricos do Amazonas - PERH/AM* - RT-03 – Diagnóstico, Prognóstico e Cenários Futuros dos Recursos Hídricos do Estado - Relatório Preliminar. Governo do Estado do Amazonas, p244-257;

TUCCI, C.E.M. (1993). "*Controle de Enchentes", in: Tucci, C. (org).* Hidrologia ciência e aplicação. Porto Alegre: Ed. da Universidade: ABRH cap 16, p621-658.: 952p;

ZEIDEMANN, V. K. (2001). *"O Rio de Águas Negras", in Florestas do Negro River.* Org. por Varella, D., Companhia das Letras, ed. USP, São Paulo – SP, pp. 63 – 72;