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USE OF FREQUENCY AND PROBABILISTIC ANALYSIS IN THE DETERMINATION OF MINIMUM REFERENCE FLOWS

REIS, Elvys Dias
Federal Center for Technological Education of Minas Gerais (CEFET-MG)
elvysreis@yahoo.com.br

SOUZA, Diego Luiz Costa
Federal University of Ouro Preto (UFOP)
diego-7-souza@hotmail.com

RESENDE, Heron Freitas
Federal Center for Technological Education of Minas Gerais (CEFET-MG)
heronfr@hotmail.com

ABSTRACT

Considering the growing concern with the reduction of water availability worldwide, studies that aim at optimized projects and fair concessions for water use become important. With this perspective, this work presents a methodology for the determination of the minimum reference flow rates ($Q_{7,10}$, $Q_{90\%}$, and $Q_{95\%}$). The Itatiba hydrological station was chosen and its flow data were collected and statistically treated for subsequent application of frequency and probabilistic analysis. The results of both analyses led to close results. The methods employed in this work can be replicated in further research.

Keywords: Linear regression. Reference flows. Statistical analysis. Water availability.

1. INTRODUCTION

The natural water availability in a hydrographic basin can be represented by the average and minimum flows, being the knowledge of these rates of great importance to plan the use and shared management of the hydric resources, minimizing the conflicts among several users (NOVAES, 2005).

Water availability is the flow that can be used in the several consumption and development activities of society, without compromising the ecological demand (CRUZ; TUCCI, 2008).

Considering the variability of water stocks in nature, sometimes with occurrences in excess, sometimes in scarcity regimes, the comparison with the demands should be made for the conditions of minimum events, as a way to ensure a full service (NOVAES, 2005). For this reason, it is necessary to know the reference water levels, that is, values estimated through minimum reference water levels that represent conditions for granting water use permits, depending on demand and water availability. The objective of these reference flow determinations is, therefore, to know the surface water supply for estimating the water availability of a given basin.

The issue of water availability has been so important that several studies have been developed worldwide, including Alvarez-Garreton et al. (2023) in Chile, Bajracharya et al. (2023) in Nepal, Hwang et al. (2023) in Canada, and da Silva et al. (2023) in Brazil, among others.

With this perspective, this manuscript aims to choose a hydrological station and determine: (i) the minimum reference water levels ($Q_{7,10}$, $Q_{90\%}$, and $Q_{95\%}$); (ii) the permanence curves for the water levels $Q_{90\%}$ and $Q_{95\%}$; (iii) the key curve for any given year; (iv) the maximum water level by probabilistic analysis for return periods of 5, 10, 20, 50, and 100 years. This work has a didactic character and its methodology can be used in future research.

2. METHODOLOGY

The Itatiba hydrological station in this study and its details, collected in the National Water Agency (ANA, from Portuguese) website, are presented in Table 1.

Table 1 – Details of the Itatiba station

Item	**Description**
Code	62675100
Name	Itatiba
Basin	Paraná River (6)
Sub-basin	Paraná, Tietê and others Rivers (62)
River	Atibaia River
State	São Paulo
Municipality	Itatiba
Responsible Party	ANA
Operator	ANA
Latitude	-22:59:0
Longitude	-46:50:0
Drainage area (km^2)	1930

2.1. Determination of $Q_{7,10}$ by frequency analysis

First, for the historical series of Itatiba station, the hydrological year was defined, as starting in the rainy month immediately after a period of small flows, or dry season. Once the year is defined, years in the historical series that contain gaps in the dry months are discarded, since this is precisely when the minimum flows occur, and also those that present a large percentage of missing data. Then, the average Q_7 is calculated and the minimum values for each year are found and sorted in a column, from lowest to highest, according to an "m" order value. $Q_{7,10}$ will be the value of Q_7 for a return period of 10 years. To obtain the event order referring to $Q_{7,10}$, Equation 1 is used:

$$m = \frac{n+1}{T} \quad (1)$$

Where "n" is the number of years, and "T" is the return period. If the value of "m" is not an integer, a value immediately above and below is used and the data is interpolated to obtain an exact value.

2.2. Determination of $Q_{7,10}$ by probabilistic analysis

The $Q_{7,10}$ was determined by probabilistic analysis using the software SisCAH—Computational System for Hydrological Analysis (UFV, 2008). For this, flow data from the historical series of the chosen station are imported and the hydrological years that present gaps in the dry period and those that contain a large percentage of missing data are discarded. Once this is done, the "Statistical Analysis" tool was used and five values of $Q_{7,10}$ were obtained, each one corresponding to a type of data distribution adjustment. In this work, the Logpearson 3 distribution is adopted because, among the five ones, it was the one with the smallest variance and, consequently, the smallest data dispersion.

2.3. Determination of $Q_{90\%}$ and $Q_{95\%}$ by frequency analysis

To find the values of $Q_{90\%}$ and $Q_{95\%}$ by frequency analysis, the historical series flow data from SisCAH was imported into the software Microsoft Excel. Among all the flow values in the series, the largest and smallest will be used as the extremes of the upper and lower limits, respectively, of the class interval. For this, a number "n" of classes is chosen and the variation between the limits of each class is obtained using Equation 2:

$$\Delta x = \frac{[(Q_{max}) - (Q_{min})]}{n} \tag{2}$$

In Equation 2, "Q_{max}" is the maximum flow, "Q_{min}" is the minimum flow, and "n" is the number of intervals chosen. The lower limits of each class are then calculated through Equation 3:

$$Q_{i+1} = Q_i + \Delta x \tag{3}$$

Thus, a table with the relative frequencies of each class is constructed and a cumulative frequency column is drawn up. $Q_{90\%}$ and $Q_{95\%}$ were the flow values corresponding to the accumulated frequencies of 90% and 95%, respectively. If the values are not obtained directly from the table, one interpolates the data and finds the exact values.

2.4. Construction of the permanence curve

After building the table of the previous item, the permanence curve is plotted using the accumulated frequency values on the horizontal axis and the lower limits of the classes on the vertical axis, so that the data form ordered pairs.

The permanence flows can be obtained directly from the graph by visual inspection or a trend line that best fits the data can be added. In the latter case, once the equation of the permanence curve has been found, the values 90 and 95 are entered into it to obtain $Q_{90\%}$ and $Q_{95\%}$, respectively.

2.5. Determination of the key curve

According to Collischonn (2008), the key curve of a section is the curve that correlates the water level (elevation) and the flow. With the curve, it is possible to transform daily measurements of elevation, which are relatively inexpensive, into daily measurements of flow, which are more expensive.

To obtain the key curve it is necessary to measure the river flow in several situations—high, medium, and low flows. In this work, the key curve will refer to a single year, chosen arbitrarily.

With the elevation and flow data of the chosen year, Equation 4 can be adjusted by employing a potential regression, and the values of parameters "a" and "b" can be obtained. The curve characterizes the key curve of the section under study.

$$Q = a(H - H_0)^b \tag{4}$$

Where "a" and "b" are the parameters for curve fitting, "Q" is the flow rate (m^3/s), "H" is the height where the respective flow rate was measured, and "H_0" is the height where the flow rate is zero.

2.6. Maximum flow by probabilistic analysis

Once the historical flow series is opened in SisCAH, the data is preprocessed, discarding hydrological years with gaps in rainy periods and years with a high percentage of missing data. Then, the option "Maximums" is selected, and then "Statistical Analysis".

On this tab, it is possible to change the return period, inserting the desirable one. The program provides five results and, again, the best fit is the Logpearson 3, that is, the one that presents the smallest dispersion of the data.

3. RESULTS AND DISCUSSIONS

The results will be consequent to the following decisions: (i) by observing the historical series of the Itatiba station, it was determined that the hydrological year starts in January and ends in December; (ii) to determine $Q_{7,10}$, the hydrological year that started in 1968 was discarded, since it presented flaws in the dry season; the year 1945 was also discarded, for presenting 100% of missing data; (iii) to determine the maximum flows, it was not necessary to discard any year other than 1945, since all of them presented complete data series.

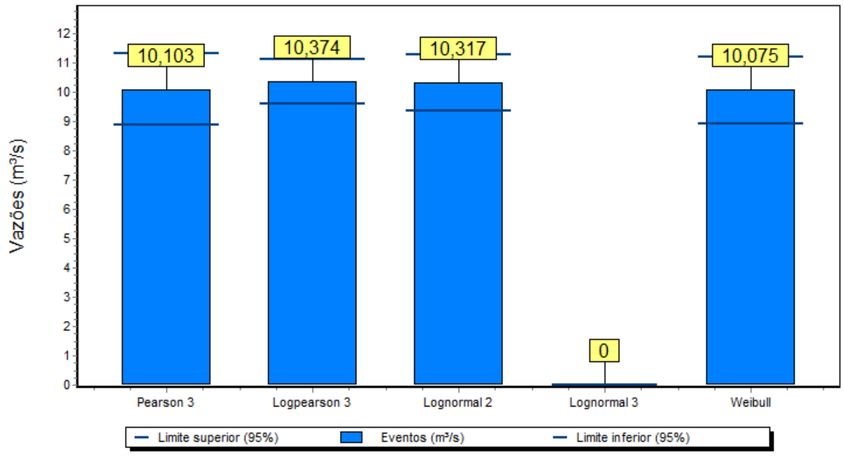
3.1. $Q_{7,10}$ by frequency analysis

Following the methodology presented in Section 2.1, the $Q_{7,10}$ obtained was 9.881 m^3/s.

3.2. $Q_{7,10}$ by probabilistic analysis

The methodology proposed in Section 2.2 led to the $Q_{7,10}$ equal to 10.374 m^3/s. Figure 1 presents the probabilistic analysis.

Figure 1 – $Q_{7,10}$ by probabilistic analysis



3.3. $Q_{90\%}$ by frequency analysis

According to the methodology presented in Section 3.3, the data presented in Table 2 was obtained for measuring the permanence flow rates.

Table 2 – Data for permanence flow rates

Classes	Upper limit	Lower limit	Absolute frequency	Relative frequency (%)	Relative accumulated frequency (%)
1	213.00	208.87	1	0.009	0.009
2	208.87	204.74	0	0.000	0.009
3	204.74	200.62	1	0.009	0.017
4	200.62	196.49	0	0.000	0.017
5	196.49	192.36	1	0.009	0.026
6	192.36	188.23	0	0.000	0.026
7	188.23	184.10	1	0.009	0.034
8	184.10	179.98	0	0.000	0.034
9	179.98	175.85	0	0.000	0.034
10	175.85	171.72	0	0.000	0.034
11	171.72	167.59	3	0.026	0.060
12	167.592	163.464	1	0.009	0.068
13	163.464	159.336	1	0.009	0.077
14	159.336	155.208	2	0.017	0.094
15	155.208	151.080	3	0.026	0.120

Classes	Upper limit	Lower limit	Absolute frequency	Relative frequency (%)	Relative accumulated frequency (%)
16	151.080	146.952	6	0.051	0.171
17	146.952	142.824	4	0.034	0.205
18	142.824	138.696	4	0.034	0.240
19	138.696	134.568	9	0.077	0.317
20	134.568	130.440	11	0.094	0.411
21	130.440	126.312	6	0.051	0.462
22	126.312	122.184	4	0.034	0.496
23	122.184	118.056	6	0.051	0.548
24	118.056	113.928	12	0.103	0.650
25	113.928	109.800	15	0.128	0.779
26	109.800	105.672	15	0.128	0.907
27	105.672	101.544	17	0.145	1.052
28	101.544	97.416	20	0.171	1.224
29	97.416	93.288	24	0.205	1.429
30	93.288	89.160	18	0.154	1.583
31	89.160	85.032	36	0.308	1.891
32	85.032	80.904	44	0.376	2.267
33	80.904	76.776	74	0.633	2.901
34	76.776	72.648	76	0.650	3.551
35	72.648	68.520	118	1.010	4.561
36	68.520	64.392	158	1.352	5.913
37	64.392	60.264	204	1.746	7.658
38	60.264	56.136	227	1.942	9.600
39	56.136	52.008	277	2.370	11.971
40	52.008	47.880	292	2.499	14.469
41	47.880	43.752	385	3.294	17.763
42	43.752	39.624	487	4.167	21.930
43	39.624	35.496	600	5.134	27.064
44	35.496	31.368	794	6.794	33.858
45	31.368	27.240	1010	8.642	42.500
46	27.240	23.112	1268	10.850	53.350
47	23.112	18.984	1806	15.453	68.803
48	18.984	14.856	1895	16.215	85.018
49	14.856	10.728	1501	12.843	97.861
50	10.728	6.600	250	2.139	100.000

Since the value of $Q_{90\%}$ is not obtained directly, it is necessary to interpolate. Thus, the value obtained for $Q_{90\%}$ was equal to 13.256 m^3/s.

3.4. $Q_{95\%}$ by frequency analysis

According to the results presented in Table 2 and analogously to the procedure of Section 2.3, $Q_{95\%}$ was found to be equal to 11.649 m^3/s.

3.5. Permanence curves for $Q_{90\%}$ and $Q_{95\%}$

Figure 2 and Figure 3 present the permanence curves for $Q_{90\%}$ and $Q_{95\%}$, in that order.

Figure 2 – Permanence curve for $Q_{90\%}$ determination

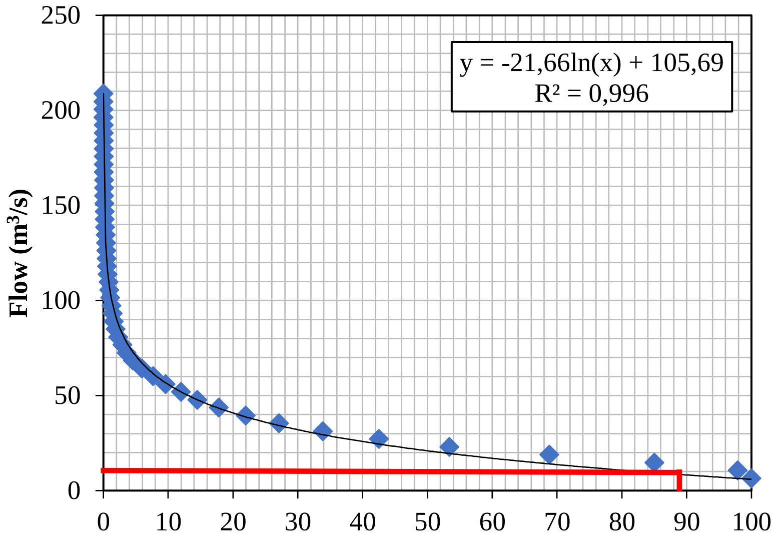
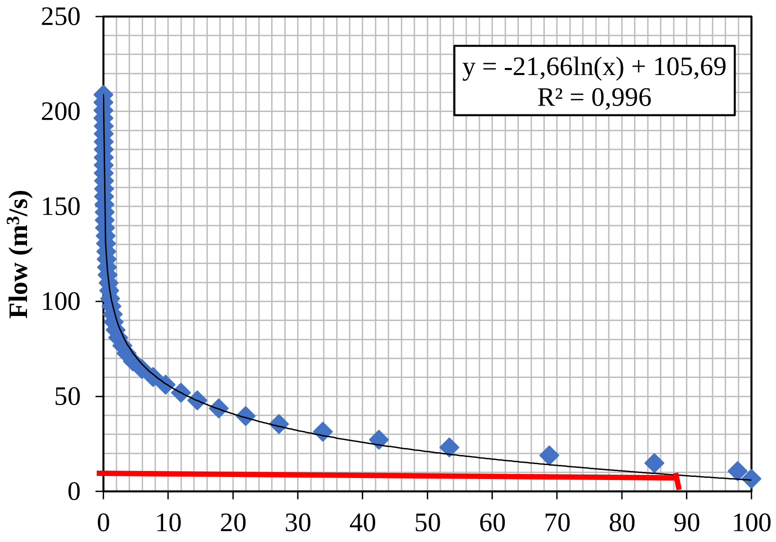


Figure 3 – Permanence curve for $Q_{95\%}$ determination

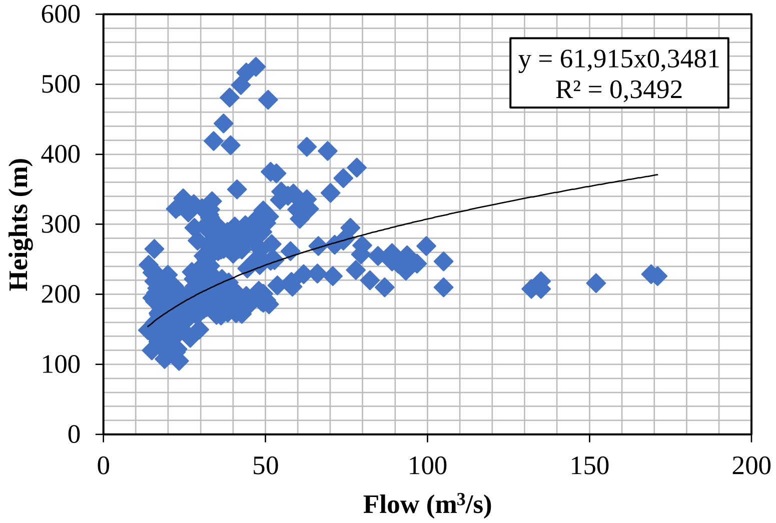


From Figure 2 and Figure 3, it is possible to measure $Q_{90\%}$ and $Q_{95\%}$ as equal to 8.22 m^3/s and 7.05 m^3/s, respectively. The coefficient of determination (R^2) above 70% (0.70) indicates that the data fit the curve well (MONTGOMERY, 2012).

3.6. Key curve

The year chosen for constructing the key curve was 1965, and the curve is presented in Figure 4.

Figure 4 – Key curve referring to the year 1965



The equation that best fits the data is shown in the graph, where "y" corresponds to the flow and "x" to the height. However, the adjustment's quality was poor since R^2 was lower than 0.70 (MONTGOMERY, 2012).

3.7. Maximum flow by probabilistic analysis

From Figure 5 to Figure 9, the maximum flow rates for return periods of 5, 10, 20, 50, and 100 years, in that order, are presented.

Figure 5 – Maximum flow referring to the return period of 5 years

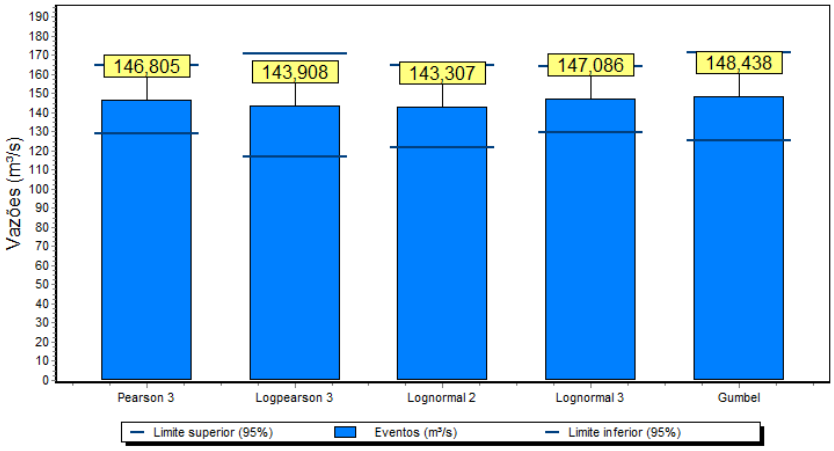


Figure 6 – Maximum flow rate related to the 10-year return period

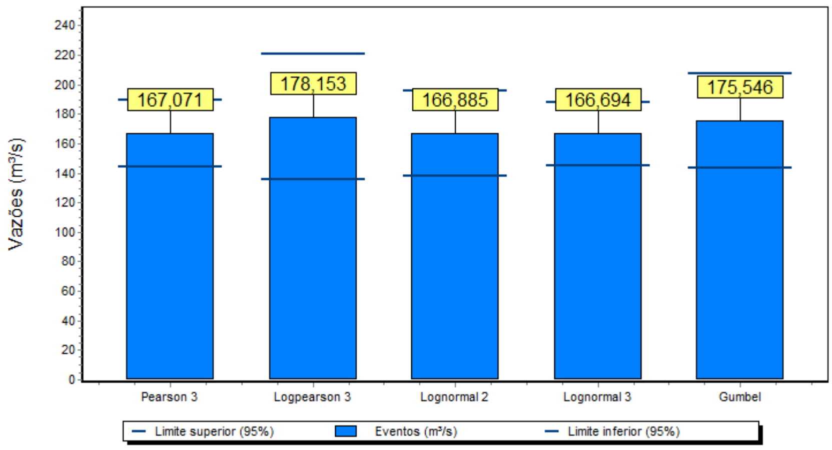


Figure 7 – Maximum flow over a 20-year return period

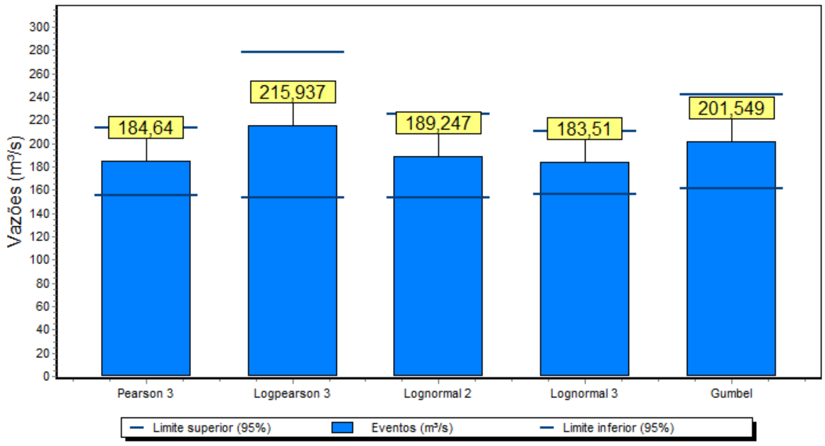


Figure 8 – Maximum flow rate at a return period of 50 years

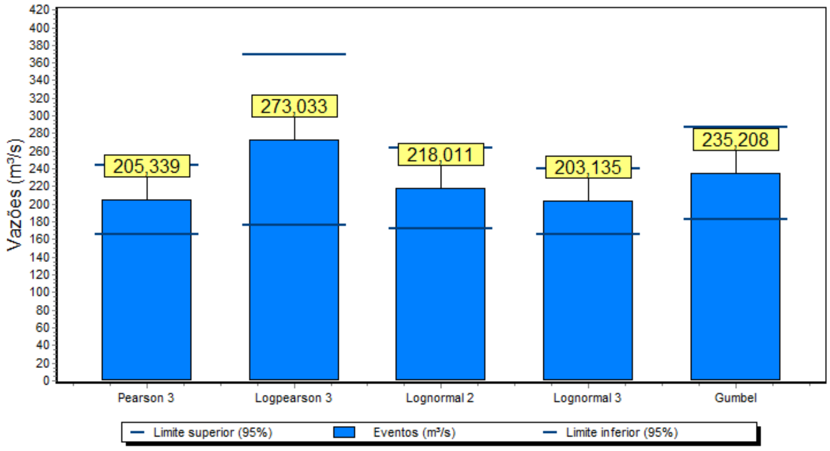
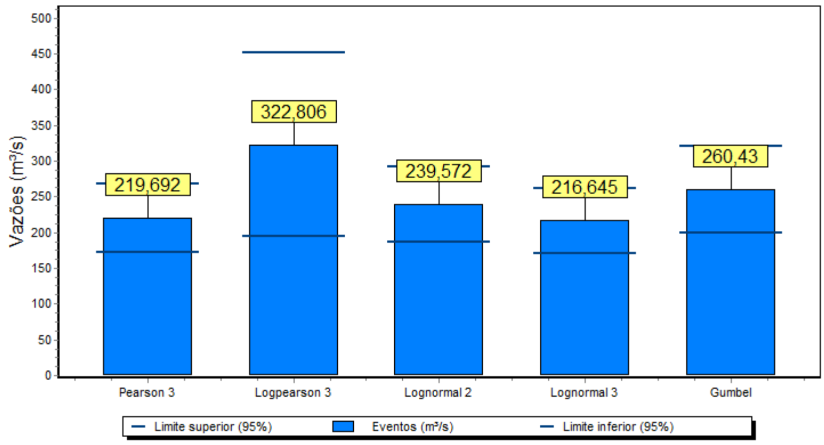


Figure 9 – Maximum flow rate at a 100-year return period



For all return periods, the maximum flow result is the Logpearson 3 distribution, Table 3 presenting the values. It is noticeable that the maximum flow rate will be higher the longer the return period is.

Table 3 – Maximum flow rate by probabilistic analysis for different return periods

Return period (years)	**Maximum flow (m^3/s)**
5	143.908
10	178.153
20	215.937
50	273.033
100	322.806

4. CONCLUSIONS

The analysis and estimation of flows from a river gaging station play an important role in the distribution and preservation of water resources. To obtain water use permits, some management agencies adopt $Q_{7,10}$ as a reference, while others adopt $Q_{90\%}$ or $Q_{95\%}$.

It can be seen that the calculation of the flows —by frequency and probabilistic analyses—resulted in close values. Furthermore, it is noted that the graphic representation of the data through the permanence curve and the key curve facilitates the understanding of the hydrological study of the river.

Therefore, it is up to the management institute to determine which is the most appropriate way of obtaining reference water levels before granting concessions.

This work has a didactic character and its methodology can be used in future research.

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