SYSTEMS & MANAGEMENT
Electronic magazine

ESTABLISHMENT OF RATING CURVES, GENERATION OF FLOW SERIES AND ESTIMATION OF MAXIMUM GRANTABLE FLOW RATES AT GUAPI-MACACU SUB-BASIN STATIONS, RJ

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ABSTRACT

The growing demand for water uses, population growth and the occurrence of extreme weather events put water availability in focus. In different parts of the world, water is no longer as abundant as it has been for decades. Human supply remains the major concern and priority in water use policy; however, sectors such as industry, agriculture and energy demand significant amounts of water, in addition to maintaining environmental systems dependent on this natural resource. All these questions highlight the current conflict regarding water use and exploitation. Integrated and sustainable management are essential foundations for the qualitative and quantitative maintenance of water resources. The grant is a legal instrument for the guarantee of water for a specified time and volume, either for the purpose of capturing or discharging effluents, and for its approval, hydrological studies are necessary to estimate the flow to be granted, also called the maximum grantable flow. The present study defined the rating curves and daily flow series of the fluviometric stations inserted in the Guapi-Macacu river basin were generated , located in the eastern portion of Guanabara Bay. Based on the results, it is proposed to adopt a new maximum grantable flow rate, aiming at a scenario of water scarcity that guarantees the integrated and sustainable use of water in the basin.

Keywords: Minimum flow rates; Water grants; Rating curve; Water resources management; Permanence curve.

PROPPI / LATEC
DOI: 10.20985/1980-5160.2019.v14n4.1585

Electronic Journal of Management & System
Volume 14, Number 4, 2019, pp. 464-482
DOI: 10.20985/1980-5160.2019.v14n4.1585

1. INTRODUCTION

Population growth, climate change and increased use of water resources have led to vulnerability of water security in the world's basins. Appropriate measures need to be taken to minimize water scarcity, improve quality and promote equitable sharing of water resources between society and nature (Kattel, 2019).

The European Environment Agency (EEA 2018) estimates that about one third of the European Union's territory is permanently or temporarily exposed to water stress. Countries like Greece, Portugal and Spain already have severe droughts during the summer months, but water scarcity is also starting to be a problem in the northern regions, including parts of the UK and Germany.

For effective water management and meeting current and future freshwater demands, water resources must be properly managed. It is ideal to consider social aspects such as public acceptance, culture and regional history, as well as economic aspects, investments in infrastructure and water technology for the planning of sustainable protection of natural ecosystems (Shen; Varis, 2000).

In Europe, the effort to control water quality resulted in the publication of the Water Framework Directive in 2000, the main instrument of the European Union's water policy, by the European Parliament. The document lays down procedures for the protection of continental surface waters, transitional waters, coastal waters and groundwater, with a view to achieving good status for springs within fifteen years, by setting progressive targets (European Union; Council of the European Union, 2000).

In the United States, the Clean Water Act (CWA) establishes the basic structure that regulates surface water quality standards. CWA incorporates quality control criteria to protect aquatic ecosystems from the harmful effects of hydrological change. One of its programs, Water Quality Standards (WQS), in particular, includes water quality criteria to protect designated uses that influence aquatic life and human health from maximum concentration criteria defined according to specific minimum flow rates (U.S. EPA, 2017).

The management of water resources in Brazil is based on the basic legal frameworks of the Water Code, established by Federal Decree No. 24,643, of July 10, 1934, the Federal Constitution of 1988, and the Federal Law No. 9,433, of January 8, 1997, entitled Water Law.

As an instrument of the Water Resources Policy (Water Law), the grant was implemented to ensure quantitative and qualitative control of water use. It guarantees the granted user the right of access to water, as it regulates its use in a watershed. The grant is an administrative act provided by the granting public authority (Union, states or Federal District), which confers the applicant the right to use water resources, pre-determining the volume of water to be used for a certain period of time (Brasil, 1997).

Given the need for knowledge and consequently the mathematical formulation for the definition of this volume of water and the associated time interval, the concept of granting derived the terms: Maximum flow grantable call VMO, ecological flow and water availability (Hora, 2012).

From the grounding of these three variables, this study will address the case study of the Guapi-Macacu Watershed, located in the state of Rio de Janeiro that goes through a situation of water stress, where more water is required than it is available in the basin (UFF/FEC, 2010). The water conflict in the sub-basin translates into being directly linked to the supply of 2.5 million people, having economic importance in the area of agriculture, and being located within it the Rio de Janeiro State Petrochemical Complex (COMPERJ – *Polo Petroquímico do Estado do Rio de Janeiro*).

This paper proposes the adoption of a new value for VMO, which helps in a more equitable management between the different uses of water resources and the natural aquatic ecosystems. In addition, it seeks to demonstrate the difficulty experienced in in the state of Rio de Janeiro regarding water management and monitoring.

2. THEORETICAL FOUNDATION

Granting of concessions in Brazil

The first legislation to deal with the appropriation and use of water in Brazil was the Water Code, Federal Decree No. 24,643, of July 10, 1934 (Brazil, 1934). Today, Brazil's water resources management is based on the Brazilian National Water Resources Policy (PNRH – *Política Nacional de Recursos Hídricos*), defined in Law No. 9,433 of January 8, 1997, entitled "Water Law". The PNRH has implemented principles for integrated management and billing, recognizing water resources as a well-endowed economic asset, with the aim of encouraging conscious use for maintaining and preserving water availability (Brazil, 1997). According to the National Water Agency (ANA, 2017), water uses in Brazil are mainly focused on irrigation, human and animal supply, industries, power generation, mining, aquaculture, navigation, and tourism and leisure.

The competence for granting the concession occurs according to the dominance of the water body where the effluent will be captured or released. Thus, for federally-owned

Electronic Journal of Management & System
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DOI: 10.20985/1980-5160.2019.v14n4.1585

water bodies, the issuance of the granting acts is attributed to ANA, and for waters owned by the states and the Federal District, requests must be directed to the state water resources management bodies (ANA, 2013). According to Santos and Cunha (2013), this decentralized policy consists of prerogatives aimed at better use of water.

VMO is the one that is available for use in a watercourse, defined based on analysis of historical series of daily or monthly average flow rates, supplemented by statistical studies, frequency analysis and, where necessary, regionalization of data (UFF/FEC, 2010).

The VMO or the volume to be granted is determined according to the reference flows adopted by the managing bodies, respecting the dominance of the water bodies (Silva et al., 2006).

In the present study, criteria will be used as a reference for the granting of concessions from the State Environmental Institute (INEA - *Instituto Estadual do Ambiente*), the current state body that manages water resources of the Rio de Janeiro.

Reference discharge

According to Brandt et al. (2008), the indicators of consumptive use are determined based on statistical analyzes of long fluviometric series capable of describing the magnitude and temporal variation of flows and hydrological regime. Understanding the frequency and duration of extreme hydrological events is critical to the efficient management of water resources, whether flooding or drought (Kroll et al., 2004).

For Tasker (1987), minimum flows are fundamental in water supply planning and projects. The analysis of environmental impacts, economic impacts, and modeling of stream water quality all contribute to improving the level of understanding of natural and regulated water flow systems. The use of minimum flows as a reference tends to ensure the subsistence of the local ecosystem, which for Richter et al. (2003) is achieved when ecological integrity is protected.

Estimation of reference discharge

Based on CONAMA Resolution No. 357/2005, the reference flow is the flow rate attributed to the VMO (Brazil, 2005). Silva and Monteiro (2004) conclude that the most used reference flows correspond to the minimum flows, which are responsible for indicating a water scarcity condition in a watercourse.

According to Hora (2012), two approaches have been more widely used as a criterion for defining reference flows: $Q_{7,10}$ and Q_{95}. $Q_{7,10}$ represents the estimate of the lowest average flow rate over a period of seven consecutive days, with an average recurrence interval of 10 years, obtained by adjusting a statistical distribution (Gumbel, Weibull or another) (Bof et al., 2013). Q_{95} is the minimum flow rate which is 95% of the time exceeded and is statistically calculated from the permanence curve of its historical series (Young et al., 2000).

Rating curve

There are several methods for measuring the liquid discharge of a watercourse. Except for some specific cases, it is not possible, in practice, to know the flow directly at a given time, and the measurements are time consuming and expensive. To know the flow over time a relationship is established between the height of the water level and the flow (*h/Q*), since it is much easier to measure said height. Knowing this relationship (rating curve) allows continuous measurement of discharges to be replaced by continuous measurement of water level (height) (Tucci, 2009). According to Tucci (2009) to determine the rating curves it is necessary to know a certain number of flow-rate pairs measured under real conditions

The relationship between quota and discharge is presented in three commonly associated forms: the graphical representation, the mathematical formula, and the calibration table (Jaccon; Cudo, 1989).

In the graphical representation, the h versus Q is represented by the curve plotted on a rectangular axis system usually in the form $h=f(Q)$. A more usual form is a potential described in Equation 1, where h is the ruler level corresponding to the flow Q; h_0 is the level to which the flow is zero; and a and b are constants determined for a local (Jaccon; Cudo, 1989).

Equation 1: $\mathbf{Q = a\,.\,(h - h_0)^b}$

The rating curve trace is the most important and most complex part of preparing calibration curves. The basic problem is drawing a curve that best fits the plotted points. It is indispensable that when the flow measurements are plotted they are identified by dates in an auxiliary table or in the graph itself (Brazil, 1982).

In general, the number of measurements is insufficient and/or the distribution is inadequate and the calibration curve incomplete; thus, it must be extrapolated at its extremities. The logarithmic extrapolation used in the present study basically consists in applying to the upper

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and lower part of the curve an adjustment of an potential mathematical expression (such as Equation 1), graphically determining the value that rectifies the upper part of the curve and extrapolates the straight line (Jaccon; Cudo, 1989).

From the rating curve and the water level values it is possible to generate the historical flow series that serve as the basis for projects of different water uses, and is indispensable for the sustainable management of water resources (Santos et al., 2009).

Permanence Curve (Q_{95})

The permanence curve describes the relationship between the flow of a watercourse and its frequency of occurrence over time. The procedure for obtaining the curve for each river station is based on the frequency analysis associated with each flow rate, which is determined by arranging the flow time series in descending order and the cumulative frequency determination (Fi), associated with each flow value, based on Equation 2, where N_{Qi} is the flow order number N_T and is the total number of flow data, which is equal to the number of days or months in the historical series (Bof et al., 2013).

Equation 2: $F_i = \frac{N_{Q_i}}{N_T}.100$

Weibull distribution ($Q_{7,10}$)

The Weibull distribution is quite suitable for the case of minimum flows, as it is inferiorly limited. In this case, the two-parameter Weibull distribution is used, in which the cumulative probability function is given by Equation 3. Its result is obtained from Q_7 of each year, which is made from a series of daily average flows, calculating the lowest moving average of seven consecutive days for each year of the series (ANA, 2011).

Equation 3: $\boldsymbol{F(x) = 1 - e^{(-x/\beta)^{\alpha}}}$

Let and be the shape and scale parameters, respectively, and the flow rate. The estimate of and are made based on the coefficient – CV (CV = standard deviation/mean) – of the minimum flow series Q_7 and using an auxiliary table shown partially in Table 1 (Von Sperling, 2007).

In order to facilitate the calculations without the need for the auxiliary table, Equations 4 and 5 were used. For their formulations, a regression analysis of α and $A(a)$ was performed as a function of CV. The quality of the adjustments is shown to be valid by the coefficient of determination R^2. With the values of α and $A(a)$, the value of β is calculated by Equation 6. Therefore, once the Weibull distribution parameters (α and β) have been estimated, the flow (x) corresponding to a return period T_r, can be calculated using Equation 7 (Von Sperling, 2007).

Table 1. Auxiliary relations for the estimation of Weibull distribution parameters

1/a	A(a)	CV
0,000	1,0000	0,0000
0,005	0,9971	0,0063
0,010	0,9943	0,0127
0,015	0,9915	0,0190
0,020	0,9888	0,0252
0,025	0,9861	0,0315
0,030	0,9835	0,0376
0,035	0,9809	0,0438
0,040	0,9784	0,0499
0,045	0,9759	0,0559
0,050	0,9711	0,0619
0,055	0,9687	0,0679
0,060	0,9664	0,0739
0,065	0,9641	0,0798
0,070	0,9619	0,0857
0,075	0,9597	0,0915
0,080	0,9575	0,0973
0,085	0,9554	0,1031
0,090	0,9433	0,1088
0,095	0,9467	0,1146

Source: Adapted from Von Sperling, 2007.

Equation 4: $\alpha = 1{,}0122\ CV^{-1{,}0779}$; *with* R^2=0,9998

Equation 5: $\boldsymbol{A(\alpha) = 0,09982 - 0,4419.CV + 0,4360.CV^2}$; *with* R^2=0,9972

Equation 6: $\boldsymbol{\beta = {}^{\overline{x}}/_{A(\alpha)}}$;

Equation 7: $\boldsymbol{X_t = \beta[-ln\left(1 - \frac{1}{T_r}\right)]^{1/\alpha}}$;

3. MATERIALS AND METHODS

Study area

The municipality of Guapimirim and part of the municipalities of Cachoeiras de Macacu, Itaboraí and São Gonçalo are part of the Guapi-Macacu Watershed, which has a drainage area of about 1257 km². The basin is responsible for supply-

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ing the municipalities of Niterói, São Gonçalo, Paquetá and part of Itaboraí, involving a population of about 2.5 million inhabitants (UFF/FEC, 2010).

The basin is bordered to the north and northwest by the Serra dos Órgãos and its foothills, to the northeast by the Serra de Macaé de Cima, to the east by the Serra da Botija and Monte Azul and to the south by the Serra do Sambé and Garcias (Brasil, 2001).

From the morphological point of view, the Macacu River basin, upstream downstream, is the escarpment and reverse of the Serra do Mar, followed by coastal hills and massifs and small area of coastal trays and finally large areas of coastal plains and patterned fluvial accommodation (Benavides et al., 2009).

From the construction of the Immunana Canal to drain the often flooded lowland areas, the natural course of the Macacu River was diverted to the Guapimirim River (UFF/FEC, 2010). The Macacu River, the largest in the region, with its main source located at about 1,700m altitude, flows into the mangroves of Guapimirim Environmental Protection Area (APA). The Guapimirim River has its springs at 2,000m altitude, and receives the waters of the Macacu at the end of the Immunana channel, flowing into Guanabara Bay. The Guapiaçu River, with springs at 1,200 meters, runs more or less parallel to the Macacu River until it meets it at the beginning of the Immunana Channel (Benavides et al., 2009).

Data survey

Fluviometric Stations

The survey and analysis of rainfall data were not added to the study, since the minimum flows generated for the calculation of the VMO tend to reflect a scenario of dryness and intense drought. Currently, sub-basin water monitoring is carried out by a network of 12 river stations, according to the inventories of the national and state water resources management agencies, ANA and INEA, respectively.

In Brazil, as the collection of fluviometric data was predominantly established by energy users, the implemented networks prioritized sites with potential for hydroelectric power production (ANA, 2013). However, the monitoring network of the Guapi-Macacu Watershed, even though it has no potential for hydroelectric power generation, puts it at a reference level in the national scenario.

This benchmark position has not prevented the network from experiencing failures, scrapping and management issues over the years. Among the sub-basin stations, some have intermittent periods of data in their historical series due to interruptions in their maintenance. This situation was mitigated later with the transfer of stations to other managing bodies and/or installation of new equipment in the same

Figure 1. Guapi-Macacu sub-basin - main drainage network and water monitoring network.

Source: Prepared by the authors from Google Earth.

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section of the river. Table 2 shows all the fluviometric stations in the basin.

Of the 12 stations surveyed, only one is managed by ANA, and the other eleven by INEA. Since 2014, these eleven are the responsibility of the agency's Flood Alert sector, through which they received investment and visibility due to the flood rates in the state of Rio de Janeiro during the rainy season.

Parque Ribeira station is the only one of the conventional type, which has a linimetric ruler in the cross section of the river, which is read daily at 7am and 5pm by an observer hired. In the other eleven stations, which are managed by INEA and classified as automatic stations, the water level reading is performed every 15 minutes from an automatic linigraph and the results are sent via telephone signal (GPRS) to the INEA database. Even though these are automatic stations, they have linimetric rulers in the river sections for equipment calibration and eventual flow measurements.

Historical Series

In order to acquire the historical series of INEA stations it is necessary to make an application to the agency, while the location of the stations is possible through access to the Flood Alert System, available on the website http://alertadecheias.inea.rj.gov.br. Regarding ANA's stations, the location and acquisition of data are made directly by Portal HidroWeb (http://www.snirh.gov.br/hidroweb/apresentacao) belonging to the agency.

After data acquisition for each station, it was found that only Parque Ribeira station (59240000) has a daily historical flow series. The other eleven stations have only water level historical series; therefore, it is necessary for this study to generate the rating curves to transform them into daily flow historical series.

Given the proximity of the Rio de Janeiro State Water and Sewage Company (CEDAE) Dam Station (59248900) to Guanabara Bay and the temporal evaluation of its historical level series, the suspicion of backwater occurrence in the section was raised. Consequently, the station was excluded from the study.

Flow Measurements

To generate rating station curves, quantifying flow measurements is a fundamental information of plotting the graph and then plotting the curve. A number of measurements representing the temporal variation of water flow in the cross section of the watercourse are needed, characterizing the dry and flood periods, and following, the generation of historical water level series in flow series from the rating curve equation found for each station.

The Anil (2242438) and Caboclo (2242440) stations have a number of measurements that are unable to represent the water behavior in the river section; thus, it is not possible to draw a representative curve for such stations. Therefore, these were also excluded from the study.

Rating curve tracing

In order to trace the rating curves, generate the respective potential equations of each station and series for flow series, Excel software was used, specifically the Solver tool.

After plotting the measurements on a two-dimensional graph (x, y), it was necessary to obtain the parameters and , determined by linear regression, and the parameter , found by trial and error. These steps were facilitated by the use of the Solver tool, which resulted in a better curve tracing and

Table 2. Stations present in the Guapi-Macacu Watershed and percentage of failures in the historical flow series

Station Name	Code	River	Latitude	Longitude	Managing body
Anil	2242438	Anil	-22,50	-42,85	INEA
Barragem da CEDAE	59248900	Canal de Imunana	-22,66	-42,93	INEA
Caboclo	2242440	Caboclo	-22,49	-42,83	INEA
Cachoeiras de Macacu	59235002	Macacu	-22,48	-42,65	INEA
Duas Barras	59242000	Guapiaçu	-22,46	-42,76	INEA
Guapimirim	2242439	Guapimirim	-22,60	-42,96	INEA
Japuíba	59237000	Macacu	-22,56	-42,69	INEA
Orindí	59245200	Iconha	-22,55	-42,89	INEA
Parque Ribeira	59240000	Macacu	-22,59	- 42.74	ANA
Quizanga	59245002	Guapiaçu	-22,56	-42,84	INEA
Soarinho	2242441	Soarinho	-22,61	-42,67	INEA
Tatu	2242437	Tatu	-22,62	-42,68	INEA

CEDAE: Rio de Janeiro State Water and Sewage Company; INEA: State Environmental Institute; ANA: National Water Agency.

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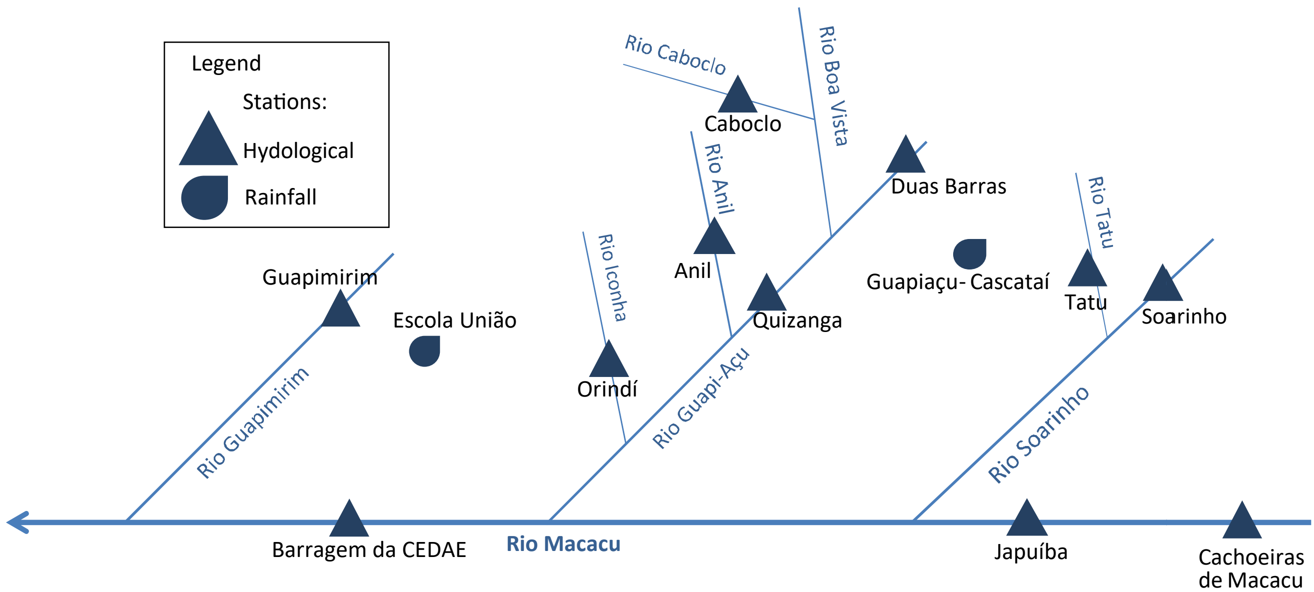

Figure 2. Drainage network diagram of the Guapi-Macacu River Basin with its monitoring network

Source: Prepared by the authors.

automatically adjusted the parameters, which were later manually refined, seeking a better correlation between the calculated flow (*Qcalc*) and the observed flow (*Qobs*). Such process follows the following steps:

- Data organization as shown in Table 3;
- Estimate initial values for parameters , and ;
- Calculations in the "***Qcalc (m³/s)***" column from the Equation 1:
- Calculations of quadratic deviations between observed and calculated flows in column "***(Qobs-Qcalc)***²", with the last cell being the sum total of the differences;
- Insert a scatter plot and plot two data series, the first of type *Qobs x h* and the second of type *Qcalc x h*, the second plotted in line format;
- Use the Solver tool, targeting the minimum value for the total sum of the quadratic differences (last cell of column "***Qobs-Qcalc***²"), changing the parameters , and , and as a constraint that h_0 and as a constraint that h0 is less than or equal to the smallest *h* measured.

Table 3. Solver Usage Reference Table

Date	(m)	Qobs (m³/s)	-	Qcalc (m³/s)	(Qcalc-Qobs)²

Table 4. Data Period and Daily Failures

Station	Code	Daily Failures	Period	Number of months with data
Guapimirim	2242439	40%	2016-2018	23
Orindí*	59245200	5%	1969-1978 2015-2018	139
Cachoeiras de Macacu*	59235002	2%	1931-1978 2015-2018	592
Duas Barras	59242000	6%	2014-2018	44
Japuíba*	59237000	21%	1976-1981 2014-2018	98
Quizanga*	59245002	4%	1969-1978 2016-2018	141
Soarinho	2242441	16%	2016-2018	23
Tatu	2242437	17%	2016-2018	24
Parque Ribeira	59240000	3%	1969-2018	581

* Series with intermittent data periods

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Generation of historical flow series

As previously mentioned, the historical series of ANA stations are in daily format, the result of the average of the two times read in the linimetric ruler on the river; INEA stations do not have daily series, since the measurement interval occurs every 15 minutes.

INEA stations were required to adapt their series to the daily format. Thus, as it occurs with ANA stations, the daily level was assigned to the average level record at 7am and 5pm each day.

Calculation of the minimum $Q_{7,10}$ and Q_{95}

For the calculation of minimum flows, only stations with historical series of flows from ten years of data were used: Oríndi (59245200), Cachoeiras de Macacu (59235002), Japuíba (59237000), Quizanga (59245002) and Parque Ribeira (59240000).

Estimates of the reference flows $Q_{7,10}$ and Q_{95} were made according to the Weibull probability distribution and permanence curve, respectively. Q_{95} can be estimated from daily or monthly data series. In the present work, both series were used for analysis and comparison of their results. For $Q_{7,10}$ the results were analyzed from the Weibull distribution adjustment, with a 10-year called $Q_{7,10}$ Weibull and also the values found by reading the plot point graph (pp) of the flows observed for the 10-year called $Q_{7,10}$ pp.

4. RESULTS AND DISCUSSION

Rating curves

Following the previously described rating curve and plotting methodology, the rating curve equations were generated for the Guapimirim (2242439), Orindí (59245200), Cachoeiras de Macacu (59235002), Duas Barras (59242000), Japuíba (59237000), Quizanga (59245002), Soarinho (2242441), Caboclo (2242440), and Tatu (2242437) stations.

Table 5 shows the generated rating curve equations and the respective determination coefficients; the graphs of the curves are given in Appendix A.

Minimum flow rates $Q_{7,10}$ and Q_{95}

Noting that for the calculation of the minimum flows $Q_{7,10}$ (Weibull and plot point) and Q_{95} (daily and monthly) only the stations Oríndi (59245200), Cachoeiras de Macacu (59235002), Japuíba (59237000), Quizanga (59245002) and Parque Ribeira (59240000) were used, and their results are shown in Table 6. Appendix B presents the graphical results of the estimated flow Q7,10.

Table 5. Rating curve equations

Station	Code	Curve equation	R²
Guapimirim	2242439	Q = 0,786 x (h-0,000)2,96	0,986
Orindí	59245200	Q = 6,624 x (h-1,129)3,00	0,951
Cachoeiras de Macacu	59235002	Q = 17,20 x (h-0,550)3,00	0,836
Duas Barras	59242000	Q = 6,770 x (h-0,510)2,38	0,995
Japuíba	59237000	Q = 4,374 x (h-0,340)2,78	0,979
Quizanga	59245002	Q = 7,901 x (h-0,330)1,34	0,998
Soarinho	2242441	Q = 8,081 x (h-0,469)3,00	0,998
Tatu	2242437	Q = 1,496 x (h-0,254)2,02	0,999
Caboclo	2242440	Q = 4,528 x (h-0,143)1,45	0,977

Table 6. Minimum flow rates $Q_{7,10}$ and Q_{95}

Station	Code	Q7,10 Weibull (m³/s)	Q7,10 pp (m³/s)	Q95 Daily (m³/s)	Q95 Monthly (m³/s)
Orindí	59245200	0,41	0,38	0,69	0,81
Cachoeiras de Macacu	59235002	0,51	1,47	2,08	2,28
Japuíba	59237000	0,35	0,13	0,51	1,01
Quizanga	59245002	1,18	1,90	2,74	3,22
Parque Ribeira	59240000	1,96	2,20	2,98	3,56

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Calculation of reference flows

From the calculated minimum flows, percentage variations of the reference flows were estimated in order to find the value that best represented the VMO of the Guapi-Macacu Watershed.

According to INEA Resolution No. 171 of March 27, 2019 (State of Rio de Janeiro, 2019), the VMO in the state of Rio de Janeiro, for surface water use of the watercourse next to the section of interest, changes its 50% reference flow rate from $Q_{7,10}$, provided for in SERLA Ordinance No. 567 of May 7, 2007 (State of Rio de Janeiro, 2007), to the 40% reference flow rate of Q_{95}.

According to CPRM (2002), for Sub-Basin 59, in which the Guapi-Macacu River Basin is inserted, 70% of Q_{95} is a good approximation to the value of $Q_{7,10}$. Given this, the 70% approximations of Q_{95} (daily and monthly) were made and the percentage differences between $Q_{7,10}$ were made from the Weibull statistical approximation, shown in Table 7. This was also done for $Q_{7,10}$ pp (Table 8).

Regarding the flow rates $Q_{7,10}$ of the Weibull statistical distribution, it can be concluded that the smallest percentage difference found was between $Q_{7,10}$ (Weibull) and 70% of Q_{95} (daily) from Japuíba station (59237000), in the value of 2%. In the monthly Q_{95}, in turn, Japuíba station (59237000) obtained a difference of 104%, a result that will be discussed later. For the other stations, the difference ranged from 6% to 187%.

From Table 8, with the $Q_{7,10}$ pp, a smaller difference was obtained compared to 70% of daily Q_{95} for Cachoeiras de Macacu (59235002) and Quizanga (59245002) stations in the value of 1%, and variation between 5% and 168% in other stations.

In search of the best fit between $Q_{7,10}$ and Q_{95}, based on the former SERLA Ordinance (State of Rio de Janeiro, 2007) which predicted the 50% reference flow of $Q_{7,10}$ for VMO in the state of Rio de Janeiro, the 50% approximations of $Q_{7,10}$ were made and the 35% and 30% approximations of Q_{95} (daily and monthly) were compared. Table 9 lists the results for the approximations cited.

The percentage difference between the values of 50% of $Q_{7,10}$ (Weibull and Plot Point) between the two approximations of Q_{95} (daily and monthly) to 35% and 30% were included in Tables 10 and 11.

The Orindí station had a smaller difference between 50% of $Q_{7,10}$ Weibull and 30% of Q_{95} daily, with a value of 11%. Parque Ribeira had the best fit, with a difference of 3% between 50% of $Q_{7,10}$ from the plotted point and 30% of Q_{95} monthly. Cachoeiras de Macacu and Quizanga, in turn, obtained the best fit between 50% of $Q_{7,10}$ from the plotted point with 35% of Q_{95} for daily values.

Japuíba station recorded a 2% difference between the 50% approach of $Q_{7,10}$ Weibull and 35% of Q_{95} daily; however, for all other values compared, the station presented values ranging from 12% to 434%. Due to the large variations in

Table 7. 70% percentage difference of $Q_{7,10}$ (Weibull) and Q_{95} (daily and monthly).

Station	Code	$Q_{7,10}$ Weibull (m³/s)	70% of Q_{95}		Percentage difference	
			Daily (m³/s)	Monthly (m³/s)	$Q_{7,10}$ – 70% Q_{95} daily	$Q_{7,10}$ – 70% Q_{95} monthly
Orindí	59245200	0,41	0,49	0,57	17%	37%
Cachoeiras de Macacu	59235002	0,51	1,46	1,60	187%	214%
Japuíba	59237000	0,35	0,35	0,71	2%	104%
Quizanga	59245002	1,18	1,92	2,25	62%	90%
Parque Ribeira	59240000	1,96	2,09	2,49	6%	27%

Table 8. Percentage difference of 70% of $Q_{7,10}$ pp and Q_{95} (daily and monthly).

Station	Code	Q7,10 pp (m³/s)	70% of Q95		Percentage difference	
			Daily (m³/s)	Monthly (m³/s)	Q7,10 pp– 70% Q95 Daily	Q7,10 pp– 70% Q95 Monthly
Orindí	59245200	0,38	0,49	0,57	29%	50%
Cachoeiras de Macacu	59235002	1,47	1,46	1,60	1%	9%
Japuíba	59237000	0,13	0,35	0,71	168%	434%
Quizanga	59245002	1,90	1,92	2,25	1%	19%
Parque Ribeira	59240000	2,20	2,09	2,49	5%	13%

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Table 9. Results of 50% of $Q_{7,10}$ by Weibull statistical distribution and plot point and 35% and 30% of Q_{95} (daily and monthly).

Station	Code	50% of $Q_{7,10}$ pp (m^3/s)	50% of $Q_{7,10}$ Weibull (m^3/s)	35% of Q_{95}		30% of Q_{95}	
				Daily (m^3/s)	Monthly (m^3/s)	Daily (m^3/s)	Monthly (m^3/s)
Orindí	59245200	0,19	0,21	0,24	0,21	0,21	0,81
Cachoeiras de Macacu	59235002	0,74	0,25	0,73	0,62	0,62	2,28
Japuíba	59237000	0,95	0,17	0,18	0,15	0,15	1,01
Quizanga	59245002	0,95	0,98	1,04	0,89	0,89	3,56
Parque Ribeira	59240000	1,10	0,59	0,96	0,82	0,82	3,22

Table 10. 50% difference in $Q_{7,10}$ (Weibull and pp) and 35% of Q_{95} (daily and monthly)

Station	Code	Percentage Difference	
		50% of Q7,10 Weibul and 35% of Q95 daily	50% of Q7,10 Weibull and 35% of Q95 monthly
Orindí	59245200	17%	37%
Cachoeiras de Macacu	59235002	187%	214%
Japuíba	59237000	2%	104%
Quizanga	59245002	62%	90%
Parque Ribeira	59240000	6%	27%
		50% of Q7,10 pp and 35% of Q95 daily	50% of Q7,10 pp and 35% Q95 monthly
Orindí	59245200	29%	50%
Cachoeiras de Macacu	59235002	1%	9%
Japuíba	59237000	168%	434%
Quizanga	59245002	1%	19%
Parque Ribeira	59240000	5%	13%

Table 11. 50% difference in $Q_{7,10}$ (Weibull and pp) and 30% in Q_{95} (daily and monthly)

Station	Code	Percentage Difference	
		50% of Q7,10 Weibul and 30% of Q95 daily	50% of Q7,10 Weibul and 30% of Q95 daily
Orindí	59245200	1%	17%
Cachoeiras de Macacu	59235002	146%	170%
Japuíba	59237000	12%	75%
Quizanga	59245002	39%	63%
Parque Ribeira	59240000	9%	9%
		50% of Q7,10 Weibul and 30% of Q95 daily	50% of Q7,10 pp and 30% Q95 monthly
Orindí	59245200	11%	29%
Cachoeiras de Macacu	59235002	15%	7%
Japuíba	59237000	129%	358%
Quizanga	59245002	13%	2%
Parque Ribeira	59240000	19%	3%

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the differences made, this station was considered to have suspicious and inconclusive results and was not included in the conclusion of the study results.

In order to correspond to a new VMO for the studied sub-basin, the results show that the smallest variation of the percentage difference was between the 50% reference flow of $Q_{7,10}$, from the plot point, and the flow of 35% daily Q_{95} reference, whose difference ranged from 1% to 29%.

5. CONCLUSIONS AND RECOMMENDATIONS

It can be concluded that in relation to the estimation for a new grantable flow for the water bodies present in the Guapi-Macacu Watershed, based on the percentage difference of the reference flows of $Q_{7,10}$ and Q_{95}, the best fit was obtained between 30% and 35% of Q_{95} with 50% of $Q_{7,10}$. This goes against the state's current VMO value, set by the regulator body in March 2019, which predicts a 40% Q_{95} reference flow for the VMO. It means that today the volume of water granted is greater than the water available, aggravating the situation of water scarcity in the region.

Therefore, it is proposed to adopt of 30% of Q_{95} as a new VMO for the Guapi-Macacu Watershed, aiming at a greener management and prioritizing the multiple uses of surface waters in the basin.

For the results found, it is noteworthy that the historical series of the stations present too many failures, and the 30-year interruption of observations and flow measurements can not represent efficiently the water regime in the basin. However, Parque Ribeira station was considered a model for the study, as it presents a historical series with 581 months without interruptions and with only 3% of daily failures. This station then underlies the proposed 30% Q_{95} reference flow rate.

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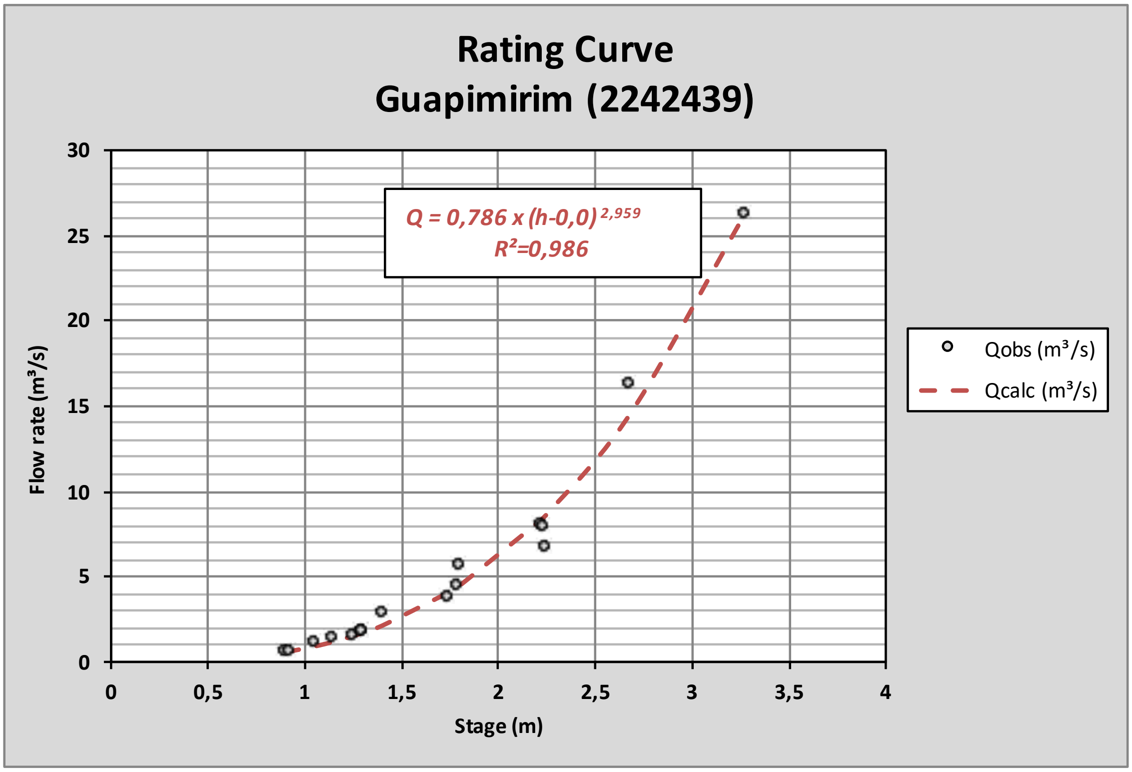
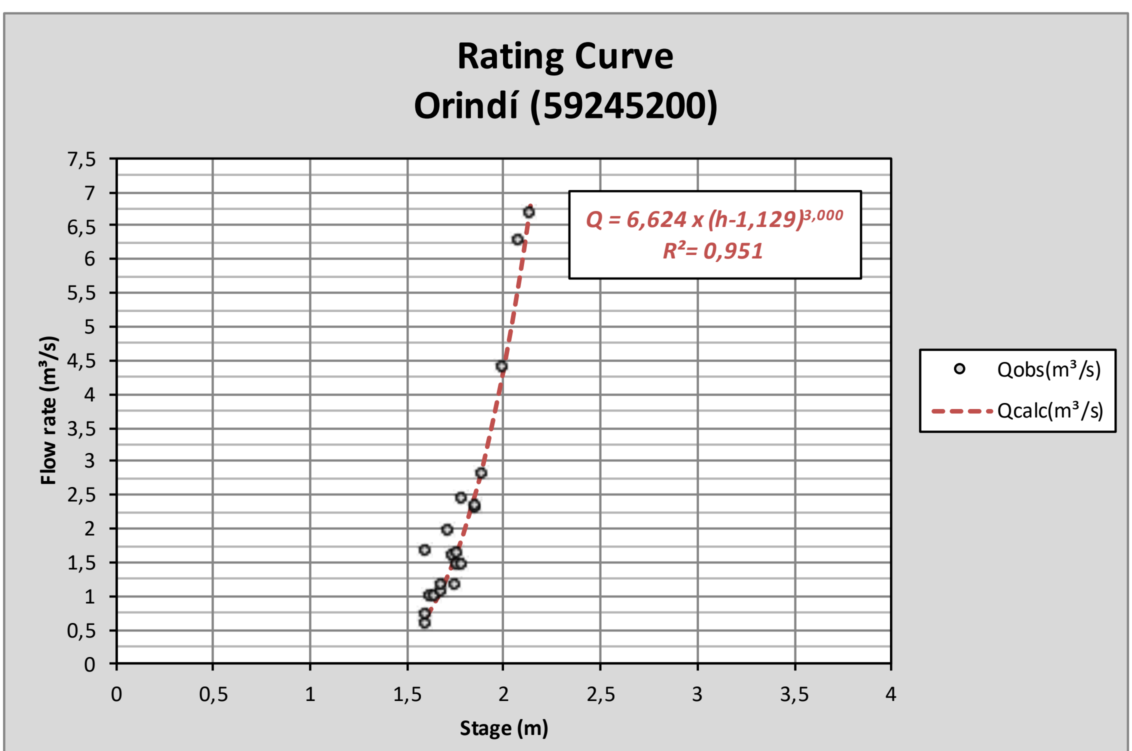
APPENDICES

Tracing the rating curves





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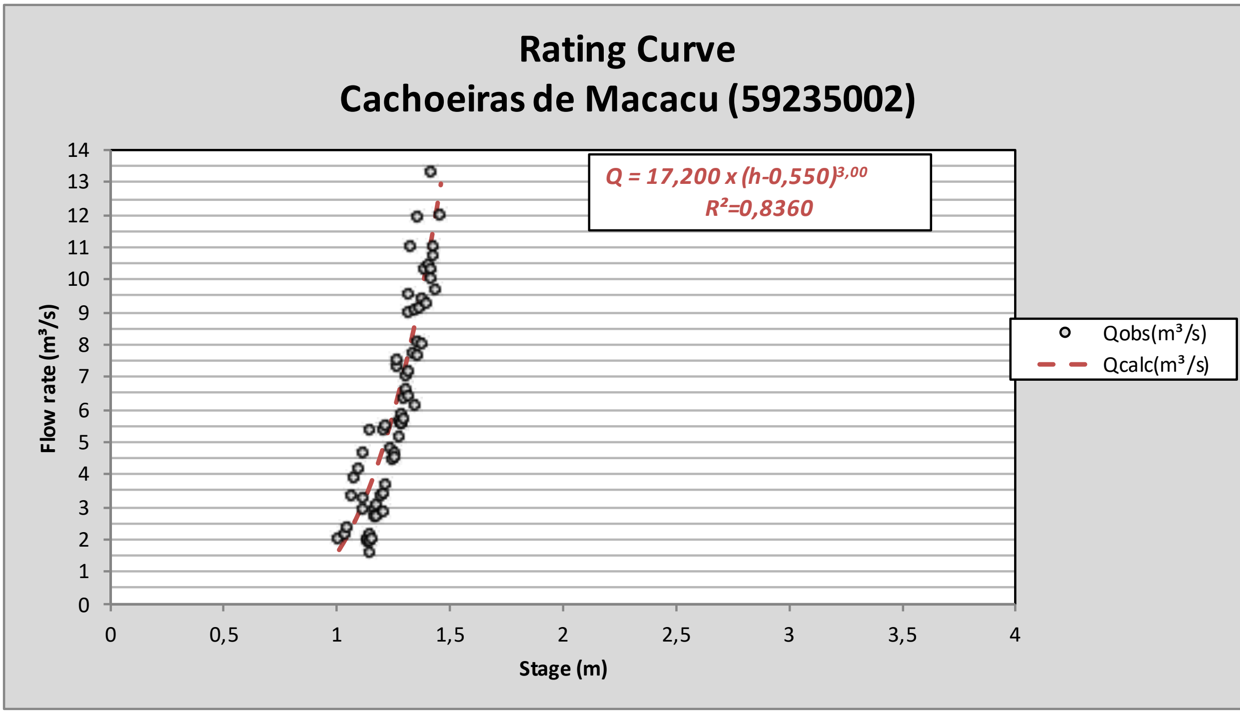

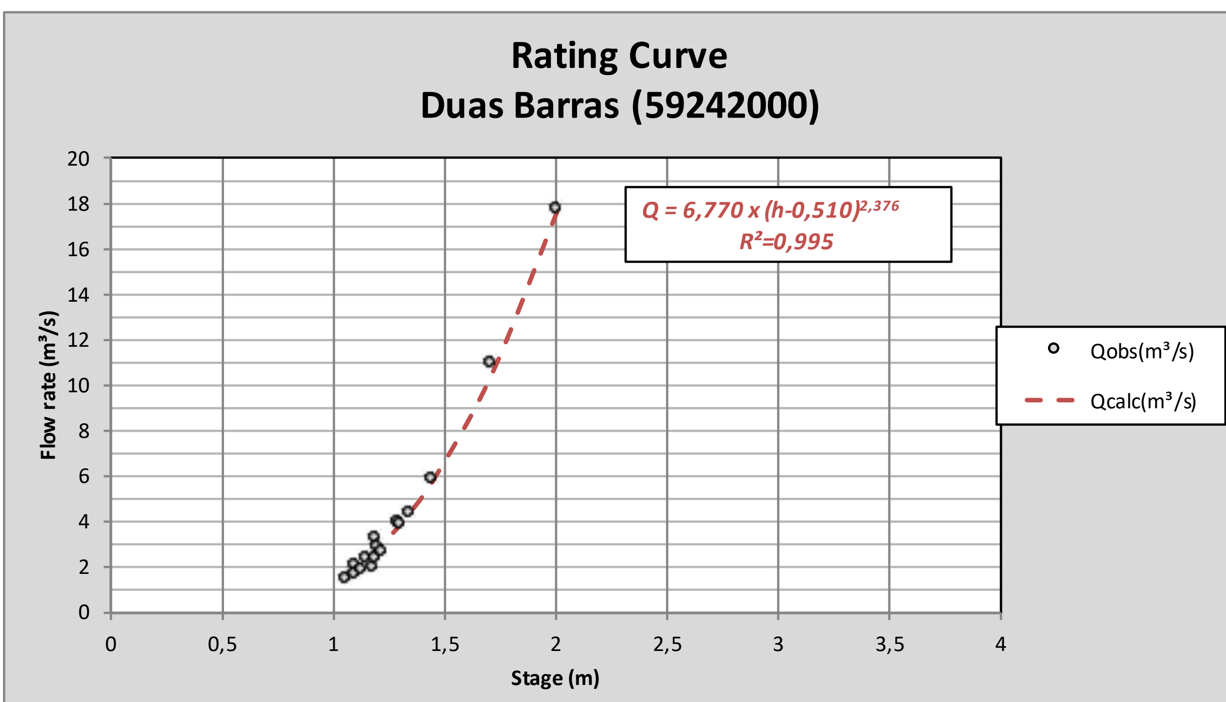

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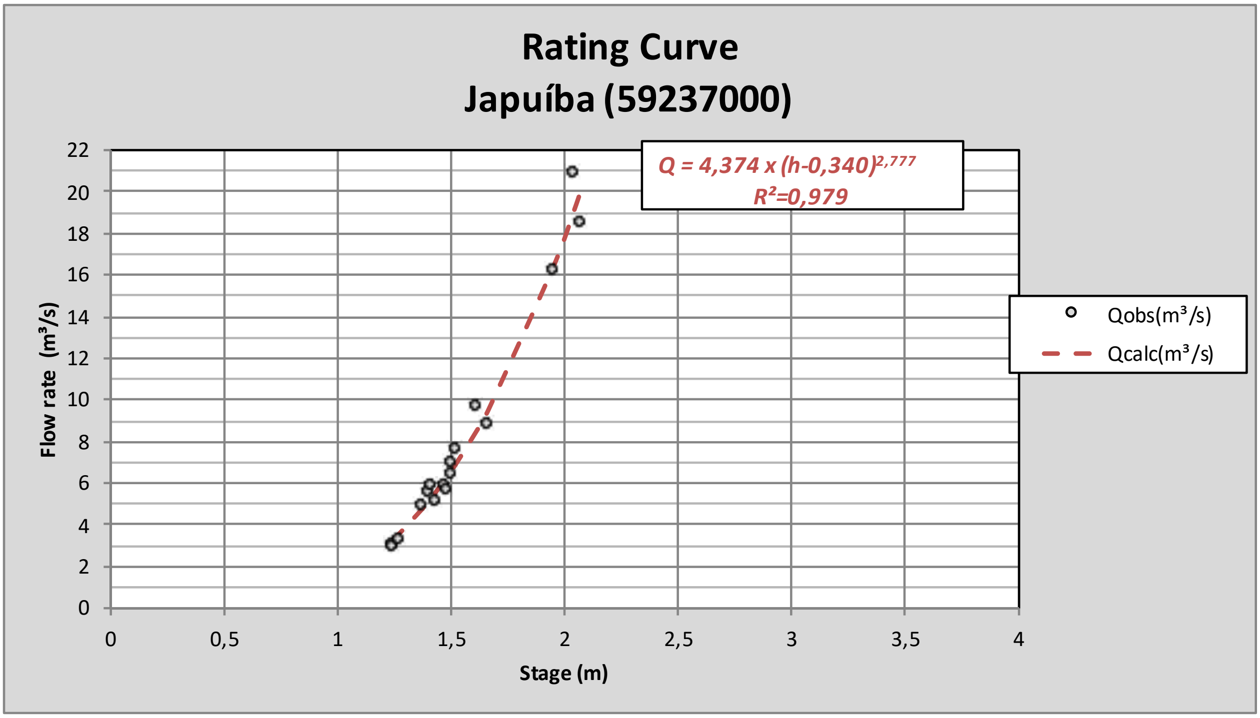

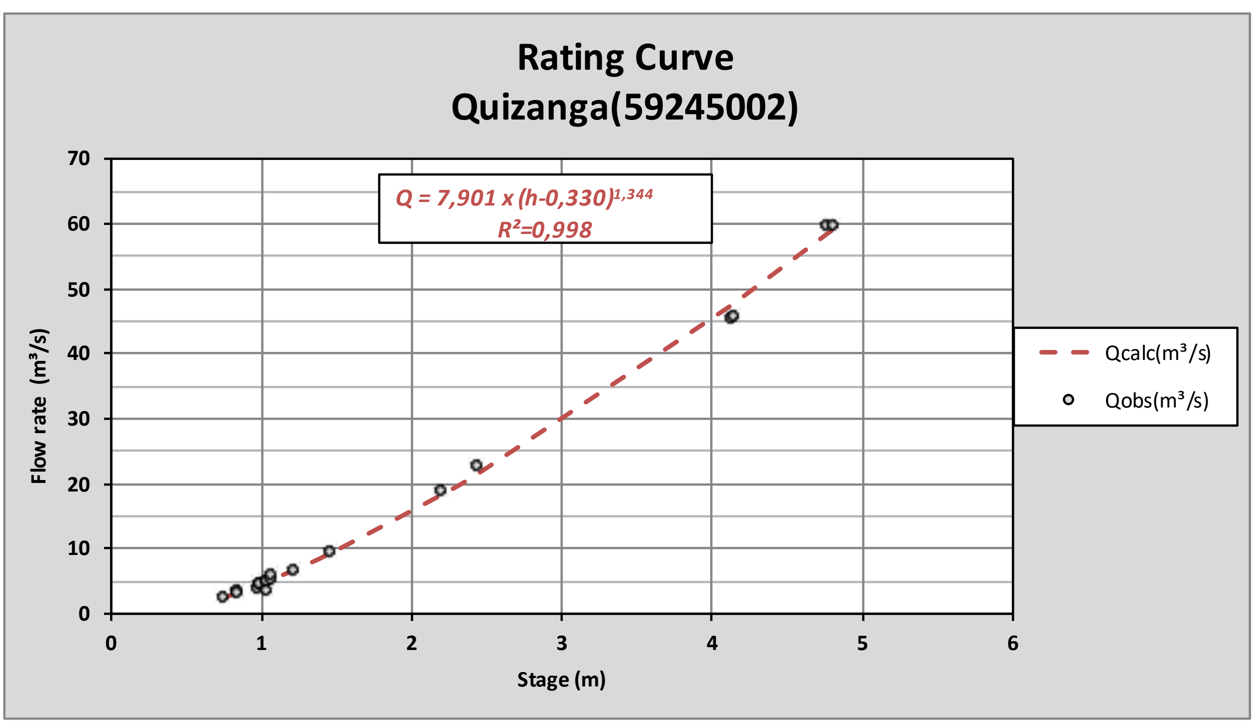

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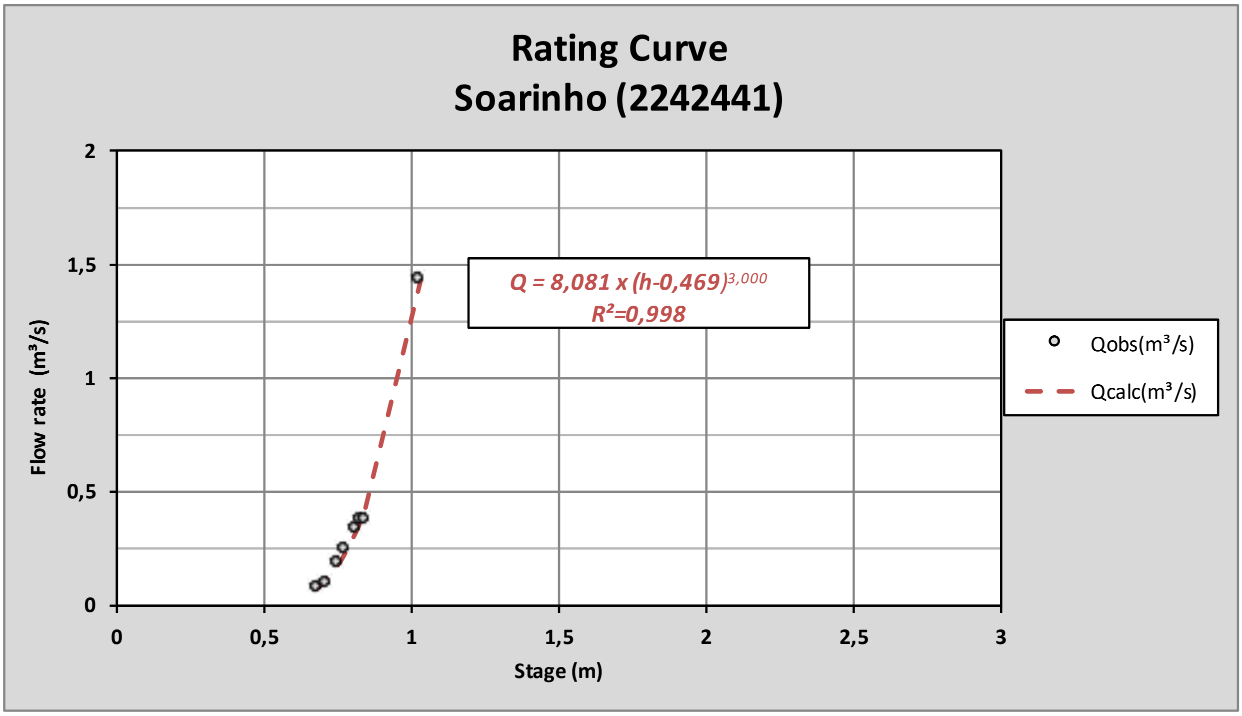

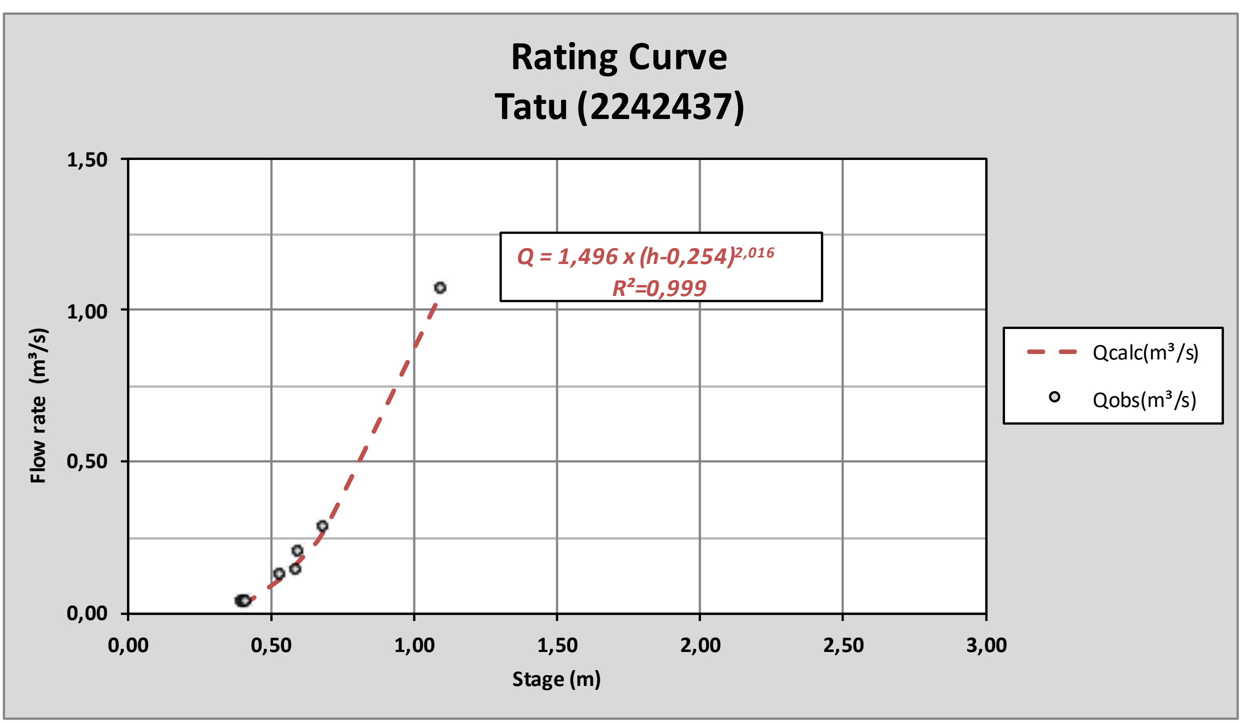

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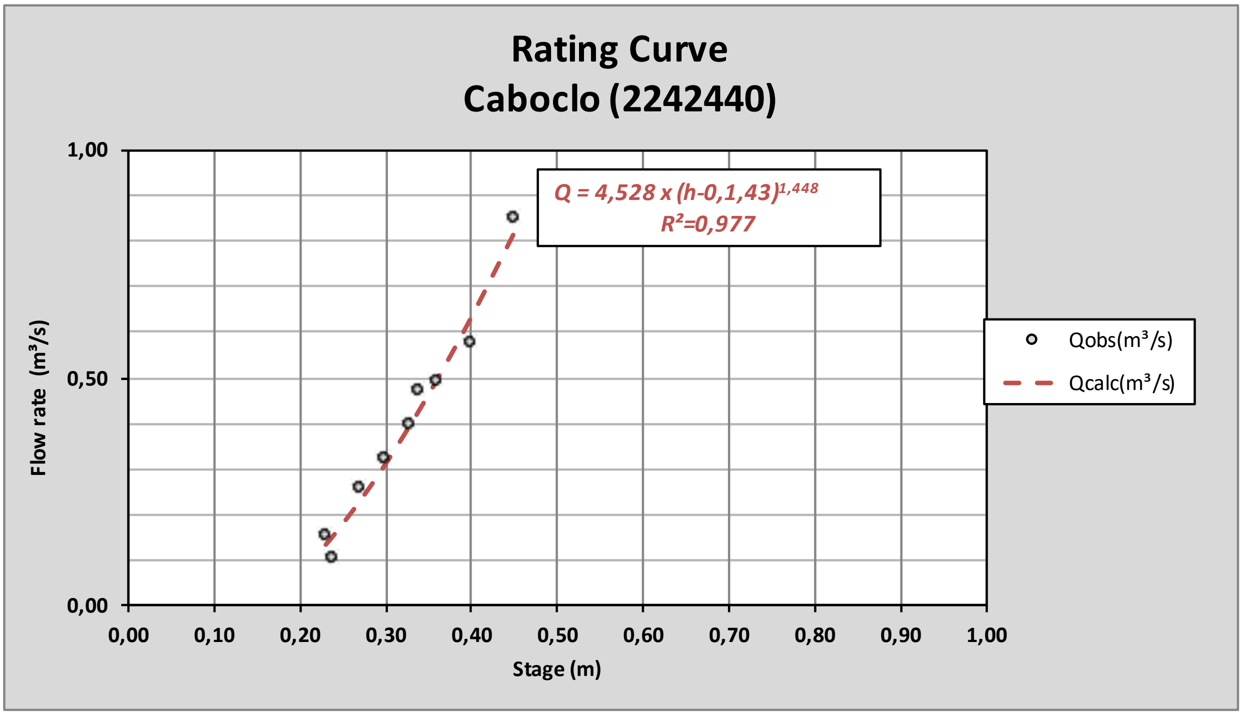
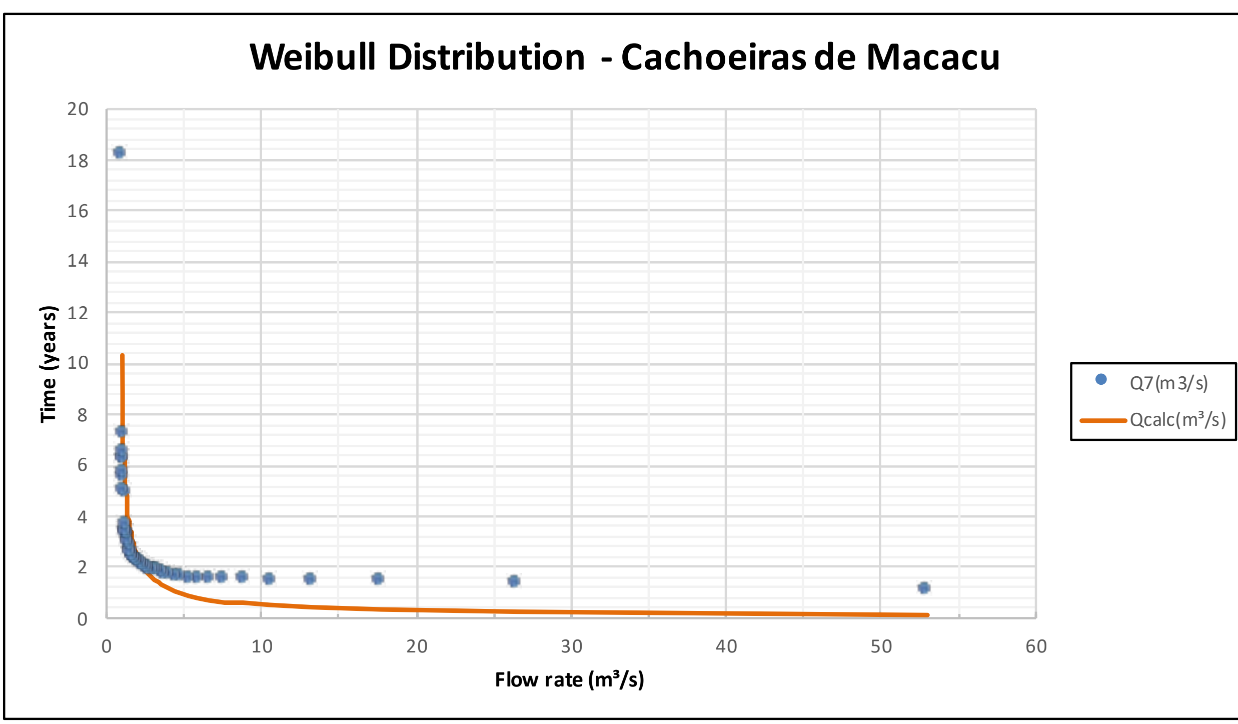


WEIBULL DISTRIBUTION ($Q_{7,10}$)
Cachoeiras de Macacu



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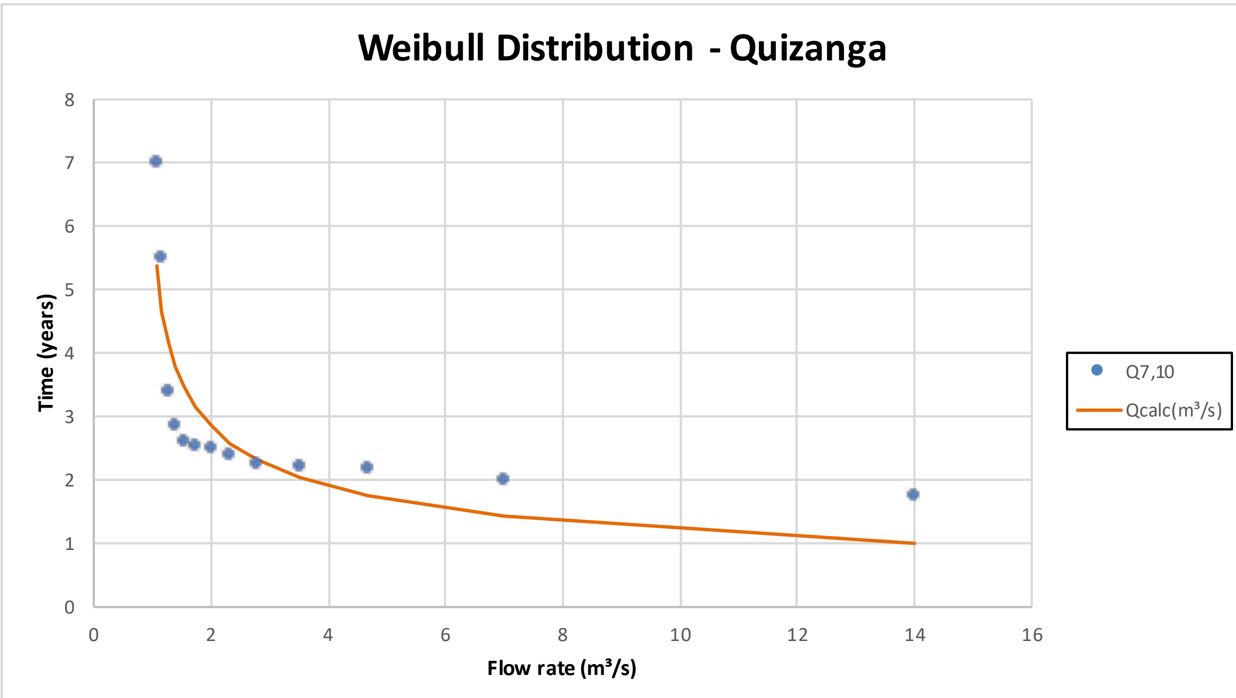
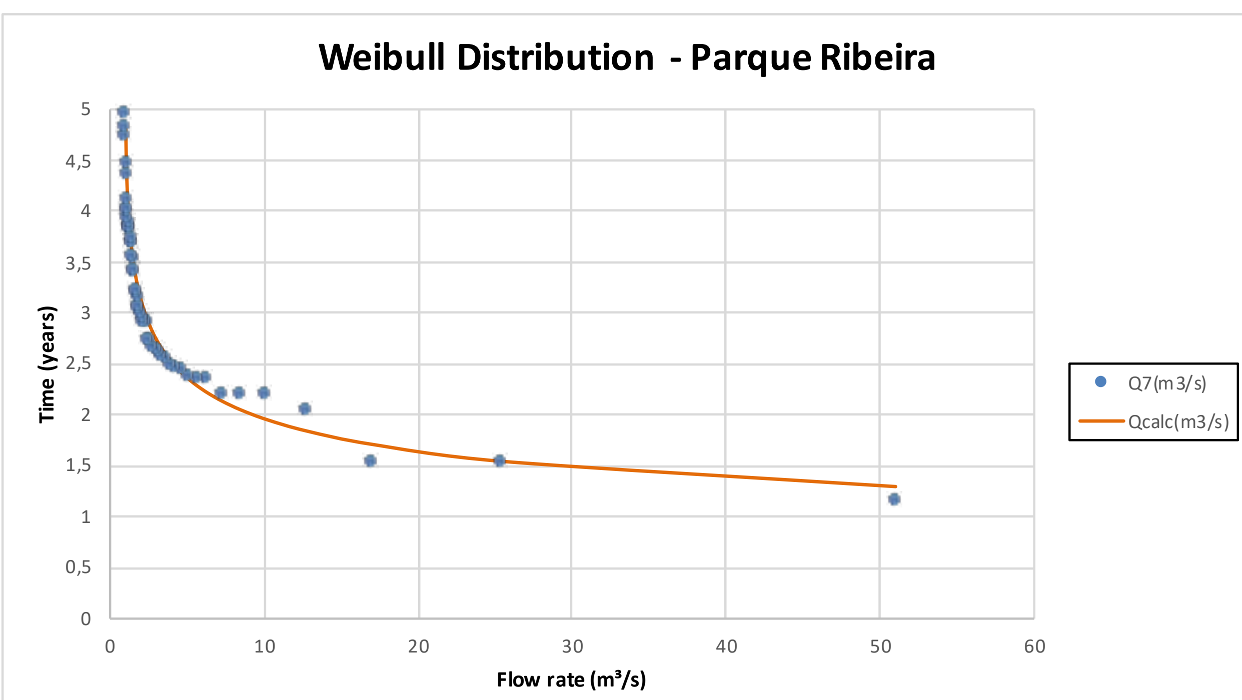
Quizanga



Parque Ribeira



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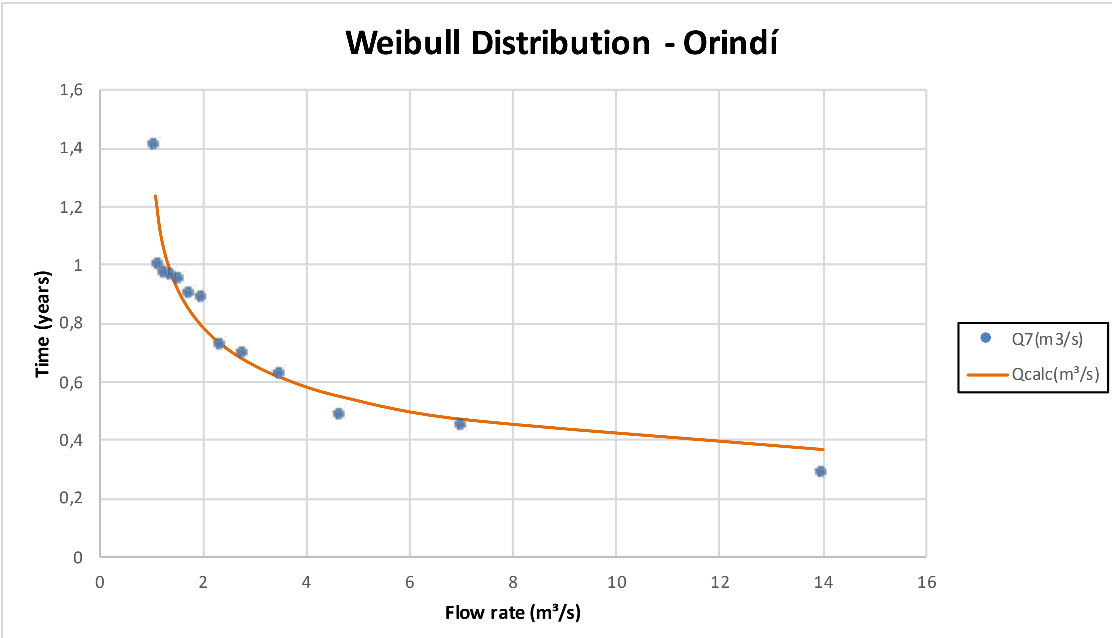
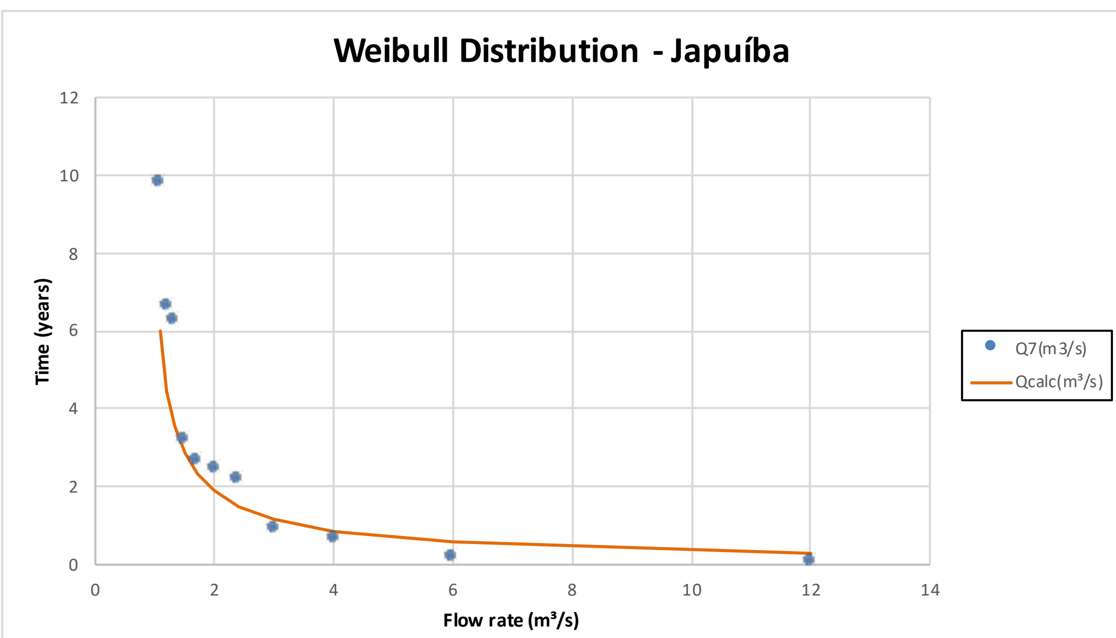
Orindí



Japuíba



Received: Oct 29, 2019

Approved: Nov 18, 2019

DOI: 10.20985/1980-5160.2019.v14n4.1585

How to cite: Novo, E. C.; Hora, M. A. G. M. (2019), “Establishment of rating curves, generation of flow series and estimation of maximum grantable flow rates at Guapi-Macacu sub-basin stations, RJ”, Sistemas & Gestão, Vol. 14, No. 4, pp. 464-482, available from: http://www.revistasg.uff.br/index.php/sg/article/view/1585 (access day month year).