:ific Journal O Saber.
ISSN: 2675-9128. Sao Paulo-SP.

Year III, v.3, ed. 1, Jan./Jul. 2023. DOI: 10.51473/ed.al.v3i1.616 | submission: 07/26/2023 | accepted: 07/28/2023 | publication: 07/31/2023

Comparisons between Methodologies for Estimating Minimum Water Flows

Reference used in Concession of Grant

Comparisons between Methodologies for Estimating minimum reference flows used in Granting Grant

Taena Roberta Poet Castilho da Silvahttp://lattes.cnpq.br/1027184677226261 Dr. Débora Cintia Marciliohttp://lattes.cnpq.br/7819552476232601 Dr. Ana Paula Oeninghttp://lattes.cnpq.br/3366592871800741
Dr. Daniel Henrique Marco Detzelhttp://lattes.cnpq.br/8287047471398895

Submission date 07/26/2023

Summary:

The State Water Resources Policy aims to guarantee control, for current and future users, of water use and its use in satisfactory quantity, quality and regime. Current legislation provides, as one of the instruments for managing water resources, the granting of the right to use water to its holder for a pre-established period and on a personal and non-transferable basis. As only part of the minimum reference flows can be granted, there is a limitation on water use. In periods of lower water availability, there is a need to analyze the influence of the seasonality of flows on the criteria for granting water use, creating alternatives for the management of water resources. In this context, the present work was carried out with the objective of evaluating and comparing the minimum reference flows. Data from five fluviometric stations in the Alto Iguaçu and Ribeira river basins, both located in the state of Paraná, were used, comparing values required by current legislation with those obtained by methodologies used mainly in the United States and Europe: Method Q_7,10, Tennant Method , Wet Perimeter Method. The results obtained allowed us to affirm that the minimum reference flows can be adjusted because the methodologies applied to the same fluviometric stations result in different values for the minimum reference flows.

Keywords: Water availability. Water resources management. Minimum reference flow.

Abstract:

The State Water Resources Policy aims to ensure control, for current and future users, of water use and its use in satisfactory quantity, quality and regime. Current legislation provides, as one of the instruments for managing water resources, the granting of the right to use water to its holder for a pre-established period and in a personal and non-transferable manner. As only part of the minimum reference flows can be granted, there is a limitation on the use of water. In periods of lower water availability, it is necessary to analyze the influence of the seasonality of flows in the criteria for granting water use, creating alternatives for the management of water resources. In this context, the present work was carried out with the objective of evaluating and comparing the minimum reference flows and verifying the possibility of an increase in water availability for different users. Data from five fluviometric stations of the Alto Iguaçu and Ribeira watersheds, both located in the state of Paraná, were used, comparing values required by current legislation with those obtained by methodologies used mainly in the United States and Europe Method, Q_7,10Tennant Method, Wet Perimeter Method.

The results obtained allowed us to state that the minimum reference flows can be adjusted since the methodologies applied to the same fluviometric stations result in different values for the minimum reference flows.

Keywords: Water availability. Water resources management. Minimum water reference flow.

1. INTRODUCTION

1.1. CONTEXT

For the adequate management of water resources in a river basin, it is necessary to know the water availability of its water bodies. The variety of interests in the use of surface waters together with the disparity in water distribution, inadequate use and low quantity of water resources can give rise to challenges and problems.

Surface water availability is commonly represented by a minimum reference flow for management purposes and represents the supply of water to be considered in the water balance, and is the granting of the right to use water resources that ensures qualitative and quantitative control of water and the right of access by different users. The grant consists of an authorization, issued by the granting public authority, for the use of water by different users of a river basin, for a predefined period.

In accordance with CNRH RESOLUTION 140, of August 21, 2012, (BRAZIL, 2012) the reference flow is the one that represents the availability of water in a watercourse, associated with a certain probability of occurrence. This definition establishes a basis for evaluating water availability in relation to user demands. In turn, RESOLUTION No. 1,938, of October 30, 2017, (BRASIL, 2017) issued by the National Water and Basic Sanitation Agency (ANA), defines users as those who carry out different uses of water resources, which are subject to preventive granting processes and rights to use water resources under the control of the Union. These uses may include abstraction and diversion of water for final consumption, use as input in production processes, transportation of ores, release of effluents for dilution purposes, transport or final disposal, fish farming in net tanks following quality parameters, accumulation of water volumes that change the flow regime or levels, and use of hydroelectric potential. These definitions establish a normative basis for the management and regulation of water resources, considering the availability, demand and different uses of water, with the aim of ensuring a balance between sustainable exploitation and preservation.

Therefore, studies that quantify reference flows are extremely important to more efficiently meet user demands and maintain a minimum flow.

The future development of hydrology requires better communication between scientists and decision makers to ensure that hydrological studies translate into actions to make water resource management more sustainable (Oki & Kanae 2006).

In Brazil, the grant is the concession instrument that guarantees the quality and quantity of water. The concession of the amount of water is given by a flow rate which, in turn, means the volume of a fluid that passes through a section for a certain period. The flow of a water body is directly influenced by rain. Periods of drought and rain change river volumes.

The minimum reference flow is associated with the minimum flows of the water body, so in order to characterize a condition of greatest possible water guarantee for users of water resources

Authorizations for water withdrawals (grants) can only occur up to the limit of this value, beyond which there may be losses in terms of water availability for other users and the maintenance of ecological balance. The grant granted to the user stipulates a maximum legal period of validity which, according to the law that Establishes the National Policy for Water Resources Management, Law No. 9,433/97 (BRASIL, 1997) is 35 years.

In general, the flow rates available in Brazil have been determined through legislation at the state and federal levels. The country's environmental and water resources legislation does not explicitly indicate the holder of the competence to define the reference flow (Silva, et al, 2005).

The minimum reference flows adopted for grant purposes, by water resources management bodies, directly influence the total available for grant. The criteria for analyzing grant requests used by management bodies are based on different minimum reference flows, as well as on the percentages considered grantable (SILVA; SILVA; MOREIRA, 2015b). When using, in a granting process, a fixed value in all months of the year, seasonal variations in water availability are disregarded, resulting in the granting of very restrictive flows in periods of greater availability (BOF et al., 2010; EUCLYDES ; FERREIRA; FARIA FILHO, 2006).

Brazilian public administration defines the risk of non-service (or guarantee of service) to all users of a basin. When defining minimum reference flow by parameter ��%,for example, there is a minimum flow value that must be guaranteed for 95% of the evaluated time. In this way, the State arbitrarily assumes that, on average, users

They have a 5% tolerance to the risk of lack of water supply. The same reasoning applies to different reference percentages, such as ��%, for example.

Another methodology used for granting is the so-called flow �,��, which represents the minimum flow duration of 7 days and 10 years of recurrence time. In other words, a 10% probability of values less than or equal to this occurring in any year is assumed. Unlike the permanence-based criteria described in the previous paragraph, the �,�� requires a probabilistic approach to determine recurrence. In general, the resulting values are more restrictive than those resulting from the criterion based on permanence.

The maximum grantable flow, as shown in the grant manual used by the Instituto Água e Terra do Paraná, in a given section of a water body can be quantified quickly. However, social, economic and ecosystem characteristics of this use are not considered.

The same methods used to estimate flow are repeated among Brazilian states, that is, the same criteria are used for rivers located in different regions of the country. However, these criteria do not seem adequate to serve different states due to the need for the minimum reference flow to be adapted to the particularities and needs of the river basin.

1.2. GOALS

Main goal:

The general objective is to compare and analyze the methodology used to estimate minimum reference flows currently practiced in the Ribeira and Alto Iguaçu river basins in the state of Paraná, with other methodologies used to estimate minimum reference flows.

Specific objectives:

- Collect flow data from water bodies in the Ribeira and Alto Iguaçu river basins;
- Apply the current methodology to estimate the reference flows used in the state of Paraná to the water bodies of the Ribeira and Alto Iguaçu river basins;
- Apply the flows of water bodies in the Ribeira and Alto Iguaçu river basins to other methods (�,��; Tennant and Wet Perimeter) used to estimate flow rates of reference;

- Compare the flows obtained by the current methodology with the methodologies raised in the literature, from the perspective of meeting water use demands.

1.3. JUSTIFICATION

The grant is constituted as an instrument for rationalizing water resources, which must impose priorities for different uses, protecting urban supply and the necessary flow in times of scarcity (MEDEIROS, 2000). But the biggest current challenge is to meet the growing demand for water and at the same time, preserve the resource, which tends to be scarce. Knowledge of how the granted flow is currently calculated and identifying methods and testing criteria different from the current ones for calculation, makes it possible to reach results for granting the right to use water resources that could be the means to solve this challenge. There will always be the possibility of a given hydrological event being greater or less than a historical value already recorded. One of the main functions of hydrology is to observe events and model the frequencies of their occurrence, allowing estimates to be made. (MELLO; SILVA, 2013).

2. THEORETICAL FOUNDATION

2.1. REGULATION AND GRANT

Law No. 9,433, of January 8, 1997, establishes the National Water Resources Policy (PNRH) (BRASIL, 1997) and creates the National Water Resources Management System. This law lists among its management instruments the Granting of the right to use water resources. There is no private ownership of water in Brazil, therefore it is up to the public authorities to manage its allocation. The grant is an authorization for the use of water which, despite its administrative nature, depends on a series of technical analyses.

The granting of the right to use water resources is a classic instrument of command and control, through which the administration authorizes an individual or legal entity, public or private, to use water from a source for human or animal supply or for some activity. economic. The need for clear rights of use or ownership, in general, was enshrined in the works of Coase (1960) and Demsetz (1967).

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The legal basis for granting usage rights has developed differently in Brazil compared to other parts of the world. In Brazil, there has been a convergence towards a system in which the public administration defines a priori the risk of lack of service (or guarantee of service) to which all users of a basin are subject. When defining as “minimum reference flow” the ��%(minimum flow value that must be guaranteed for 95% of the evaluated time), for example, the State arbitrarily assumes that, on average, users have a 5% tolerance to the risk of water shortages. The minimum reference flow is associated with the minimum flows of the water body, in order to characterize a condition of greatest possible water guarantee for users of water resources. Authorizations for water withdrawals (grants) can only occur up to the limit of this value, beyond which there may be losses in terms of water availability for other users and the maintenance of ecological balance.

According to current legislation for rivers within the Union's domain, there are three types of concessions: the preventive grant, the Declaration of Water Availability Reserve (DRDH) and the grant of right of use. The preventive grant does not grant the right to use water resources and is intended to reserve the flow subject to granting, enabling investors to plan projects that require these resources. The maximum validity period of this grant issued by ANA is limited to three years. And the granting of right of use, as the name suggests, gives the holder the right to use water resources. It is interesting to note that the legislation establishes for the grant holder a period of two years to begin implementing the project, and another period of six years to complete this implementation. However, there is no need for specific authorization to start operating the project. In other words, when the entrepreneur receives the right to use grant, he can start using water resources.

2.2. HYDROLOGICAL REGIME

In a large part of Brazil, the hydrological regime is marked by seasonality, that is, there is a period of rain, in which flows are higher, and a period of drought, in which river flows are sustained only by the discharge of underground aquifers, resulting in lower flows. Thus, knowledge of the hydrological regime is fundamental for more informed decision-making in the management of water resources. Two approaches have been used nationally as a criterion for defining minimum reference flows: minimum flows with a given recurrence time and flow rates with a permanence curve.

The first approach originates in the sanitation sector and is used in several states, such as São Paulo, Rio de Janeiro and Minas Gerais, usually through a minimum flow of 10 years of recurrence and 7 days of duration (�,��), in which the minimum flow statistic is obtained by adjusting a statistical distribution, such as Gumbel, Weibull or another.

The second approach, the use of permanence curve flows, consists of ordering the observed flows and identify the flow that is exceeded in a large percentage of the time. This percentage of time is usually called guarantee. The complementary value to the guarantee, that is, the time in which it is not satisfied, is usually called risk or failure. When taking this reasoning to the limit, the minimum river flow is the ���%, that is, a flow rate lower than that has never been observed, and, therefore, which can be counted on without risk of failure. However, the ���%this is an extremely low flow rate, which would significantly limit water use. Furthermore, most users tolerate a certain level of risk of not having their demand met. For example, most irrigated crops can tolerate a few days without water. Users such as public supply have a lower risk tolerance, that is, they must be attended to a greater percentage of the time. For this reason, the minimum reference flow adopted by many states and by ANA is between ��%and the ��%.

Therefore, water availability is established based on past statistics observed at monitoring stations. Currently, water resources management activities adopt the stationarity hypothesis, that is, assuming that hydrology statistics observed in the past will be repeated in the future. Although there are criticisms of this approach, the various studies carried out within the scope of the National Water Resources Management System (SINGREH) have not yet been conclusive in proposing a procedure that incorporates sufficiently reliable predictions of future climate variability in the management of water resources.

2.3. CLASSIFICATION OF METHODOLOGIES

There are different methods for establishing the minimum reference flow, and these can be classified into four main categories: hydrological, hydraulic, habitat and holistic (Benetti et al., 2003)

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Hydrological methodologies are those that use data (time series of daily or monthly flows) to make recommendations about the reference flow. In general, they set a percentage or proportion of the natural flow to represent the minimum reference flow.

Hydraulic methodologies consider changes in hydraulic variables simple as wetted perimeter or maximum depth, measured in a single cross section of the rivers. The reference flows are obtained through a graph in which the variable under study and the flow are represented.

The methodologies that employ habitat use aim to evaluate the reference flow in relation to the physical habitat available for the species under analysis. These methodologies are a process of developing a reference flow policy that incorporates variable or multiple rules, considering the demands of water supply and other water uses. They usually involve determining a flow-habitat relationship to compare flow alternatives over time.

Holistic methodologies identify critical flow events depending on the established criteria for flow variability, for some or main components or parameters of the river ecosystem. They are basically ways of organizing and using flow data and knowledge. It is a methodology that uses distinct procedures or methods to produce results that no other procedure and/or method would produce alone.

These main classifications of methodologies demonstrate what information and considerations they use to estimate reference flows.

Examples of hydrological methodologies can be cited: ��%, The �,��and the Tennant methodology. These methods use statistical analysis of historical flow data to determine the minimum reference flow. They include flow frequency analysis, regional flow analysis, flow sequence analysis, and flow trend analysis.

As an example of hydraulic methodology, we can mention the Wet Perimeter methodology. This method considers the physical characteristics of the channel and uses hydraulic equations to determine the minimum reference flow.

2.4. METHODOLOGY USED IN THE STATE OF PARANÁ

In Paraná, following the Grant Manual created by the Superintendency of Water Resources Development and Environmental Sanitation SUDERHSA (2006), the granting of surface water abstraction to reach a maximum grantable flow in a given section of the water body follows the following formulations:

������á���= 0.5 × 95%�− �ã� ������í��� (1)

�ã� ������í��� �= ∑ ������á����+ ∑ ��������� (two)

in which:

������á���is the maximum flow that can be granted in the section of the water body;

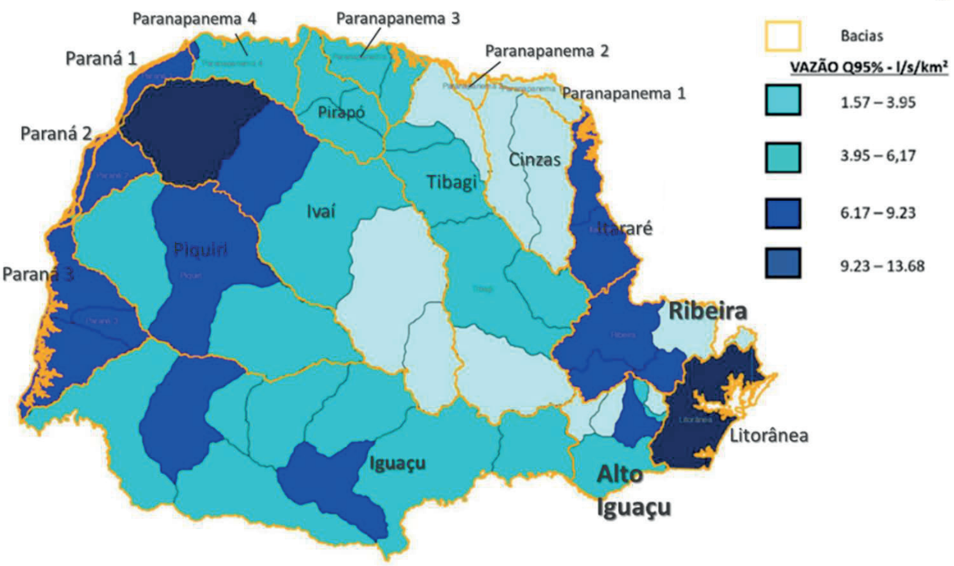
��%is the natural flow remaining 95% of the time in the section ;

∑ ������á����is the sum of the flows granted upstream of the section ;

∑ ���������is the sum of the flows granted downstream, which depend on the flow in the section ;

FIGURE 1 demonstrates the water availability of the permanent flow ��%- (l/s/km^2).

FIGURE 1 – WATER AVAILABILITY MAP / PERMANENCE FLOW ��%- (l/s/km^2)



SOURCE: State Water Resources Plan – Águas do Paraná

2.5. METHODOLOGIES THAT WILL BE USED FOR THE STUDY

2.5.1. Method �,��

Seven-Day Minimum Flow Method with a Ten-Year Recurrence Period (�,��) is included in Hydrological Methods. Only information used in this method of daily historical flows. Full name �,��work with minimum flows of seven days of duration to establish the maximum flow possible to be used by users. A �,��indicates a situation of minimal state (TUCCI, 2002).

The method �,��does not take aquatic habitats into account and its main advantage is It is not necessary to carry out any field work, other than, of course, systematic measurement of the flow.

To calculate the 7-day moving averages for each year of �,��,get the minimum value of moving averages for each year and create a new historical series with the minimum values of the 7-day moving averages for each year �,��SisCAH System software will be used Computational for Hydrological Analysis (SisCAH), version 1.0. This computer system was developed under the coordination of the Federal University of Viçosa, which allows data to be imported from ANA. OdownloadSisCAH can be done through the page of the Water Resources Research Group at the Federal University of Viçosa.

2.5.2. Tennant's method

The Tennant or Montana method was developed by TENNANT (1976), in Montana (USA), and is one of the most used hydrological methods throughout the world (BENETTI & LANNA, 2003; REIS, 2007). Tennant (1976) defined the expected conditions for the river ecosystem as a function of the ecological flow, expressed as a percentage, in relation to the average annual river flow, calculated for the location of interest.

For this methodology, the ecological flow will be considered as the minimum flow of reference, as this flow will be the flow capable of maintaining adequate environmental conditions throughout the water course, the specific characteristics of the water course and the demands of the river basin in question.

The method recommends a minimum reference flow based on a set of percentages in relation to the average annual flow for the river's flood and dry periods. Flow recommendations are based only on values obtained by the author of the method, as shown in TABLE 1.

TABLE 1 – FLOW REGIME RECOMMENDED BY THE TENNANT METHOD

CONDITION OF THE RIVER	Recommended flow	
	October - March (dry)	**April - September (rainy)**
Wash or maximum	200%	
Optimal Range	60 - 100%	
Exceptional	40%	60%
Great	30%	50%
Good	20%	40%
Regular or with degradation	10%	30%
Bad or minimal	10%	10%

SOURCE:TENNANT (1976)

The recommended flow rate will also be determined using the SisCAH software, version 1.0. From the data obtained in the software and the table developed by TENNANT (1976), the minimum flow and reference values were determined using the method. In the work, the suggestion of REIS (2007) was adopted, where the author highlights that in the table prepared by TENNANT (1976), the dry and rainy periods of the year are seasonally opposite in relation to those in the Southeast region of Brazil. Therefore, when applying this method to rivers in this Brazilian region, attention must be paid to this seasonal inversion.

The Tennant Method has undergone several modifications that aim to better adapt the reference flow regime calculated from the natural flow regime in several regions different from the one for which the method was developed (BENETTI & LANNA, 2003; REIS, 2007; SARMENTO, 2007).

2.5.3. Wet Perimeter Method

The Wet Perimeter Method is the third most used method in the USA to quantify ecological flows into rivers (ANA, 2004). For this methodology, the ecological flow will be considered as the minimum reference flow, as this flow will be the flow capable of maintaining adequate environmental conditions throughout the watercourse, ensuring the survival and reproduction of the species present and the maintenance of biodiversity and the specific characteristics of the watercourse and the demands of the river basin in question are being considered .

This methodology has been applied mainly to rivers that have relatively wide, rectangular and shallow cross sections and does not include an explicit representation of the aquatic habitat.

To obtain the reference flow rate, it is necessary to establish the relationship between the flow rate and the wetted perimeter. The wetted perimeter of a watercourse is defined as the length of the line of intersection of the wetted surface of the channel with the cross section normal to the flow direction.

Processes based on the relationship between hydraulic parameters and flow, although they require field data, establish very simple relationships between the hydraulic variables associated with the channel geometry and flow. The wetted perimeter and flow relationship is a function of the channel geometry and the way in which the flow increases with depth. The relationship between flow and channel geometry can be expressed using the Manning equation (Baptista et al, 2003).

= × 1/× h�× �/� �/�   (3)

in which:

=flow (m^3/s);

=Manning roughness coefficient (m/($s^{1/3}$)); = cross-sectional area of the flow (m_{two}); =slope (m/m);

h =hydraulic radius (m), obtained by:

h = ——   (4)

where:

=wet perimeter (m).

And the flow calculation using the Continuity Equation:

$$= \times \qquad (5)$$

where:

=flow (m^3/s);

=average speed (m/s);

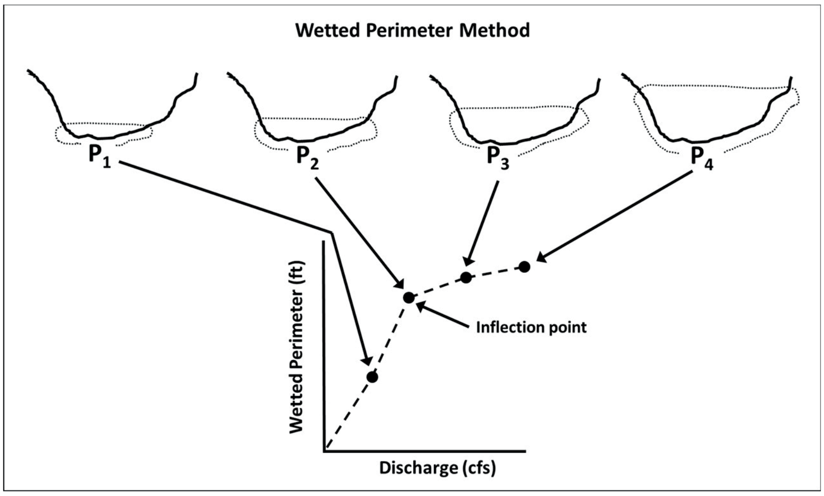
=wet area (m^2).

To apply the methodology, the cross sections are defined. Bathymetry information was obtained from field records from ANA's National Water Resources Information System (SNIRH).

After defining the sections, depth and speed measurements are taken, for at least three flows, and hydraulic simulation can be used. From the hydraulic simulation, a graph is defined that relates the wetted perimeter with the flow rate, then the main inflection point of the curve is identified, from which the increase in flow translates into a minor increase in the wetted perimeter. The flow referred to at the inflection point is the recommended flow considering the assumption that the minimum reference flow obtained in rapids areas is equally suitable for other types of habitat (Annear and Conder, 1984).

The graph generally has a characteristic shape, being more inclined for low discharges and less inclined for higher flows, as explained in FIGURE 2.

FIGURE 2 – RELATIONSHIP BETWEEN FLOW AND WET PERIMETER



SOURCE:GOPAL (2013)

This abrupt decrease is called the breakpoint ('break in slope').The breakpoints, where the variation in the wetted perimeter decreases, are used to determine the flow required to protect the habitats, that is, the reference flow (GOPAL, 2013).

A limitation to applying the wetted perimeter method approach is that it only recommends a minimum reference flow value. Ideally, a flow regime should be specified taking into account periods of flood and drought (Gippel and Stewardson, 1998).

3. MATERIALS AND METHOD

This chapter presents the materials and method used in the present work, starting with the characterization of the study area, going through the techniques used, and ending with the data used. The present study proposes an analysis of methodologies used to estimate reference flows.

3.1. MATERIALS

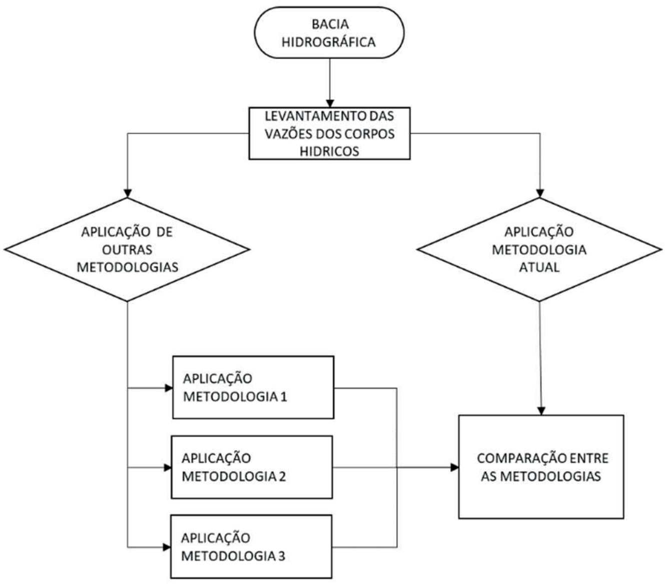
The materials necessary for the development of this work are: information (flows of water bodies in the river basins that will be studied; field records with bathymetry information) from fluviometric stations that are in the database of the National Information System on Water Resources (SNIRH) from ANA; the Computational System for Hydrological Analysis (SisCAH) software, version 1.0, system computer developed under the coordination of the Federal University of Viçosa, which allows importing data from ANA.

3.2. METHOD

The methodology applied in this study is a descriptive and comparative analysis of several experiences comparing the legal methodology used to estimate the minimum reference flow in the state of Paraná with existing methods that are different from the current one.

The method proposed in this work is presented in the Activities flowchart shown in FIGURE 3.

FIGURE 3 – ACTIVITY FLOWCHART



SOURCE: The author (2023).

3.2.1. Hydrographic basin

The first step will be to choose the basins that will be studied. In this work, the Ribeira and Alto do Iguaçu river basins were chosen, due to the importance of their locations (FIGURE 4). The main demand for these basins is for human consumption, as it is the region where approximately 43% of the state's population is concentrated.

FIGURE 4 – LOCATION OF WATER BASINS IN PARANÁ.

SOURCE: Plans for the Alto Iguaçu and Ribeira basins – Executive Report Version 03 (2014)

3.2.2. Flow survey

To survey the flows of water bodies in the Alto Iguaçu and Ribeira basins, the SNIRH database was used. There were evaluations for the choice of fluviometric stations: the evaluation of which stations were closest to the Metropolitan Region of Curitiba; evaluation regarding the minimum period of data in the historical series, the established period was 25 years, at least, of daily observations (most of the stations used have more than 30 years of data, 10 stations have records between 7 and 27 years and 41 stations have a record of more than 30 years of data); and the last evaluation for choosing the stations refers to bathymetry, with stations being chosen that have a field record containing bathymetry information in the SNIRH database. After evaluating the stations, 5 of the 51 identified were used. TABLE 2 indicates the fluviometric stations that were used for this study.

TABLE 2 – LIST OF FLOW METER STATIONS USED IN THE STUDY

Station:	**LITTLE FARM**	**Code:**	65010000	**Entity:**	A-N-A
County:	São José dos Pinhais	Installation:	01/28/1955	Extinction:	
Type:	FFrQDST	Bowl:	Iguaçu	Sub-basin:	1
Altitude:	875.060 m	Latitude:	25° 31' 09''	Longitude:	49° 08' 48''
River:	small river	Drainage area	116.82 km²	Class:	two
Station:	**BRIDGE OF CAXIMBA**	**Code:**	65019700	**Entity:**	A-N-A
County:	Curitiba	Installation:	12/18/1973	Extinction:	
Type:	FFrQDT	Bowl:	Iguaçu	Sub-basin:	1
Altitude:	865.350 m	Latitude:	25° 36' 49''	Longitude:	49° 21' 24''
River:	Barigui River	Drainage area	257.00 km²	Class:	3
Station:	**GUAJUVIRA**	**Code:**	65025000	**Entity:**	A-N-A
County:	Araucaria	Installation:	08/17/1973	Extinction:	
Type:	FFrQDST	Bowl:	Iguaçu	Sub-basin:	3
Altitude:	857.720 m	Latitude:	25° 36' 00''	Longitude:	49° 30' 48''
River:	Iguaçu River	Drainage area	2577.76 km²	Class:	two
Station:	**FERRY NEW**	**Code:**	65028000	**Entity:**	AGUASPARANÁ
County:	New Ferry	Installation:	08/17/1973	Extinction:	
Type:	FFrQDST	Bowl:	Iguaçu	Sub-basin:	3
Altitude:	854.735 m	Latitude:	25° 35' 14''	Longitude:	49° 37' 54''
River:	Iguaçu River	Drainage area	3048.69 km²	Class:	two
Station:	**CHAPEL OF RIBEIRA**	**Code:**	81200000	**Entity:**	A-N-A
County:	Adrianople	Installation:	10/20/1936	Extinction:	
Type:	FFrQDST	Bowl:	Ribeira	Sub-basin:	two
Altitude:	180,000m	Latitude:	24° 39' 20''	Longitude:	48° 59' 59''
River:	Ribeir River	Drainage area	7252.00 km²	Class:	two

SOURCE: Data taken from SNIRH

3.2.3. Applications of the current methodology used in the state of Paraná

Currently in the Paraná basins the methodology is used ��%which is classified as a hydrological method. Repeating the information contained in the theoretical foundation, these methods use statistical analysis of historical flow data to determine the minimum reference flow. They include flow frequency analysis, regional flow analysis, flow sequence analysis, and flow trend analysis.

The methodology used in Paraná obtains the ��%, through the flow permanence curve. The stay curve is a graph that represents the percentage of time that the flow of the river or stream is equaled or exceeded by a certain value. This way it is possible to estimate the minimum reference flow ��%, which represents the flow that is equalized or exceeded 95% of the time. The permanence curves are obtained from a historical record of average flows over 20 years, using the daily scale.

3.2.4. Applications of other methodologies

The other methodologies for estimating the minimum reference flow that will be used for this study are mentioned in TABLE 3. Presented previously in the theoretical foundation.

TABLE 3 – METHODS THAT WILL BE USED

Methodology	**Classification of Methodology**
�,��	HYDROLOGIC
Tennant	HYDROLOGIC
Wet Perimeter	HYDRAULIC

SOURCE: The author (2023).

3.2.5. Comparison between the methodology used in Paraná and other methodologies used

With the five fluviometric stations chosen, and with the survey of the flows of the historical series of each of these stations. The minimum reference flow value used in the state of Paraná was estimated for each of the stations and compared with the reference flow values found for each of these stations using the proposed methodologies.

The comparison between the methodologies will be quantitative through joint analysis between the current reference flows with the results of the flows from each of the methods presented in this work. The objective of this analysis will be to identify, given this comparison, which methods are most appropriate to ensure more efficient management, providing better use of available water resources.

4. CASE STUDY

4.1. WATERSHEDS

The basins used were the Alto Iguaçu basins and the Ribeira Basin.

4.1.1. Alto Iguaçu Basin

The floodplains along the Iguaçu River, located in the stretch of the Alto Iguaçu Hydrographic Basin, are prominent areas in the Metropolitan Region of Curitiba due to the need to protect and conserve them, given their function as the main water channel. drainage of the metropolitan urban territory and an important regional biodiversity corridor.

The Alto Iguaçu Hydrographic Basin has an area of approximately 2,881km^2 (18.64% of the metropolitan territory) and its river intersects the Metropolitan Region of Curitiba in an East-West direction, reaching the municipalities of Pinhais, Piraquara, Curitiba, São José dos Pinhais, Fazenda Rio Grande, Araucária, Contenda, Balsa Nova and Lapa. Paraná basin that houses the largest population concentration in the State, characterized by a continuous patch of urban occupation where approximately 97% of the metropolitan urban population lives (Central Urban Nucleus).

Curitiba's water supply system belongs to the Alto Iguaçu basin and is interconnected with six other municipalities in the Metropolitan Region of Curitiba – RMC. The main dams that store water to supply the Municipality are: Iraí, Piraquara and Passaúna. And the three Water Treatment Stations (ETAs): ETA Iguaçu; ETA Iraí and ETA Passaúna.

4.1.2. Ribeira Basin

The Ribeira do Iguape River originates on the eastern slope of the Paranapiacaba mountain range, with the main contributors being the Piedade, Pardo, Turvo, Capivari and Açungui rivers. Of its 470 km in length, 220 km are in Paraná territory. The basin is located in the northern part of the first plateau of Paraná, over aquifer-karst units.

In the state of Paraná, the flow of the Ribeira River was evaluated at the Capela da Ribeira hydrometric station, in Adrianópolis. At this point, the hydrographic basin area is 9,129km^2, and the demands for the use of water resources total 2.3 m³/s of which 81% are for public supply, 9% for industrial supply and 4% for other demands, 3% for aquaculture and 2% for irrigation. In the Ribeira River basin, 12% of the use of water resources for public supply comes from surface sources and 88% from underground sources.

4.2. FLOW DATA AND APPLICATION IN THE METHODOLOGY USED IN THE STATE OF PARANÁ

Through SNIRH, the average flows of the historical series were obtained for each fluviometric station.

By exporting the flow data from SNIRH to the SisCAH software, the software performs the calculation and presents the flows (��%) found in TABLE 4.

TABLE 4 – VALUES OF ��%

MONITORED STATIONS	**FLOW RATE**
NAME	**��%(m³/s)**
LITTLE FARM	0.75
CAXIMBA BRIDGE	0.40
GUAJUVIRA	12.7
FERRY NEW	18.1
RIBEIRA CHAPEL	48.1

SOURCE: Station data taken from SNIRH and processed using SisCAH software

Using the ��%, the criteria used in Paraná for granting purposes were used, i.e. 50% ��%showing the results in TABLE 5.

TABLE 5 – MINIMUM REFERENCE FLOW FLOWS (M³/S) FOR FLUVIOMETRIC STATIONS OF THE STUDY

MONITORED STATIONS	**MINIMUM FLOW FLOWS REFERENCE (m³/s)**
NAME	**50%** %
LITTLE FARM	0.38
CAXIMBA BRIDGE	0.20
GUAJUVIRA	6.35
FERRY NEW	9.05
RIBEIRA CHAPEL	24.1

SOURCE: The author (2023).

4.3. METHODOLOGIES USED IN THE STUDY

4.3.1. Method �,��

Survey of flows �,��for each fluviometric station in this study, it was obtained through the SisCAH software, which works with data on daily flows from the date of installation of each station until the period up to July/2022. The flow �,��is the flow average of the 7 driest consecutive days of any year, with a recurrence period of 10.

To finish calculating the �,��It is necessary to carry out a statistical analysis, with the annual values of the lowest average of 7 consecutive days, which allows finding the flow value for the 10-year return period. To find this flow value, probability distributions that best fit the observed data are used. According to Von Sperling (2007) the distributions that have been used for this purpose are Weibull, Gumbel for minimum values, Pearson type III, Log-Pearson type III, Log-Normal II Log-Normal III.

To achieve the objectives of this work, the Computational System for Hydrological Analysis (SisCAH) software checks and chooses the best adherence of these six probability distributions for the data series. For the stations in this work, the software used LogPearson Type III distributions to determine the probability of occurrence of the variables under study. Flow rates obtained �,��,reference flow rates were calculated for each fluviometric station of the study using the criteria of Ordinance No. 20/99 – SUDERHSA (DOE OF 06/16/99) which brings the maximum grantable limit, for the state of Paraná in that period, of 50% of the �,��. Flows shown in TABLE 6.

TABLE 6 - VALUES OF �,��

MONITORED STATIONS	**FLOW RATE , (M³/S)**	**FLOW RATE OF REFERENCE (M³/S)**
NAME	,	**50% ,**
LITTLE FARM	0.57	0.29
CAXIMBA BRIDGE	0.36	0.18
GUAJUVIRA	8.48	4.24
FERRY NEW	11.2	5.60
RIBEIRA CHAPEL	40.2	20.1

SOURCE: Station data taken from SNIRH and processed using SisCAH software

4.3.2. Tennant's method

TABLE 7 presents the average flows obtained for the fluviometric stations in the studies. The survey of the average flows of the historical series for each fluviometric station was obtained by SNIRH.

TABLELA 7 - FLOW VALUES OF FLUVIOMÉT STATIONS RICH

MONITORED STATIONS NAME	AVERAGE FLOW (M^3/S)
LITTLE FARM	2.80
CAXIMBA BRIDGE	5.58
GUAJUVIRA	52.3
FERRY NEW	148.1
RIBEIRA CHAPEL	116.9

SOURCE: National Water Resources Information System (SNIRH).

The average flows calculated from the stations are used in different percentages for the dry period and the rainy period according to Tennant's method (TENNANT, 1976) as shown in the TABLES TABLE8,TABLE9, TABLE10, TABLE 11and TABLE12.

TABLE 8 - FAZENDINHA - FLOW REGIME RECOMMENDED BY THE TENNA METHOD NT

FAZENDINHA - TABLE - FLOW REGIME RECOMMENDED BY THE METHOD OF TENNANT

CONDITION OF THE RIVER	RECOMMENDED FLOW RATE	
	MAY - OCTOBER (DRY)	NOVEMBER -APRIL (RAINY)
WASH OR MAXIMUM	5.60	
OPTIMUM RANGE	1.68	2.80
EXCEPTIONAL	1.12	1.68
GREAT	0.84	1.40
GOOD	0.56	1.12
REGULAR OR WITH DEGRADATION	0.28	0.84
POOR OR MINIMAL	0.28	0.28
HIGH DEGRADATION	0.00	0.28

SOURCE: The author (2023).

TABLE 9 - CAXIMBA BRIDGE - FLOW REGIME RECOMMENDED BY THE METHOD OF TENNANT

CAXIMBA BRIDGE - TABLE - FLOW REGIME RECOMMENDED BY THE METHOD DE TENNANT

CONDITION OF THE RIVER	RECOMMENDED FLOW RATE	
	MAY - OCTOBER (DRY)	NOVEMBER -APRIL (RAINY)
WASH OR MAXIMUM	11.16	
OPTIMUM RANGE	3.35	5.58
EXCEPTIONAL	2.23	3.35
GREAT	1.67	2.79
GOOD	1.12	2.23
REGULAR OR WITH DEGRADATION	0.56	1.67
POOR OR MINIMAL	0.56	0.56
HIGH DEGRADATION	0.00	0.56

SOURCE: The author (2023).

TABLE 10 - GUAJUVIRA - FLOW REGIME RECOMMENDED BY THE TENNA METHOD NT

GUAJUVIRA BRIDGE - TABLE - FLOW REGIME RECOMMENDED BY TENNANT'S METHOD

CONDITION OF THE RIVER	RECOMMENDED FLOW RATE	
	MAY - OCTOBER (DRY)	NOVEMBER -APRIL (RAINY)
WASH OR MAXIMUM	104.72	
OPTIMUM RANGE	31.42	52.36
EXCEPTIONAL	20.94	31.42
GREAT	15.71	26.18
GOOD	10.47	20.94
REGULAR OR WITH DEGRADATION	5.24	15.71
POOR OR MINIMAL	5.24	5.24
HIGH DEGRADATION	0.00	5.24

SOURCE: The author (2023).

TABLE 11 - BALSA NOVA - FLOW REGIME RECOMMENDED BY THE TENN METHOD ANT

PONTE DA BALSA NOVA - TABLE - FLOW REGIME RECOMMENDED BY TENNANT'S METHOD

CONDITION OF THE RIVER	RECOMMENDED FLOW RATE	
	MAY - OCTOBER (DRY)	NOVEMBER -APRIL (RAINY)
WASH OR MAXIMUM	296.26	
OPTIMUM RANGE	88.88	148.13
EXCEPTIONAL	59.25	88.88
GREAT	44.44	74.07
GOOD	29.63	59.25
REGULAR OR WITH DEGRADATION	14.81	44.44
POOR OR MINIMAL	14.81	14.81
HIGH DEGRADATION	0.00	14.81

SOURCE: The author (2023).

TABLE 12 - RIBEIRA CHAPEL - FLOW REGIME RECOMMENDED BY THE METHOD OF TENNANT

RIBEIRA BRIDGE - TABLE - FLOW REGIME RECOMMENDED BY THE METHOD OF TENNANT

CONDITION OF THE RIVER	RECOMMENDED FLOW RATE	
	MAY - OCTOBER (DRY)	NOVEMBER -APRIL (RAINY)
WASH OR MAXIMUM	233.80	
OPTIMUM RANGE	70.14	116.90
EXCEPTIONAL	46.76	70.14
GREAT	35.07	58.45
GOOD	23.38	46.76
REGULAR OR WITH DEGRADATION	11.69	35.07
POOR OR MINIMAL	11.69	11.69
HIGH DEGRADATION	0.00	11.69

SOURCE: The author (2023).

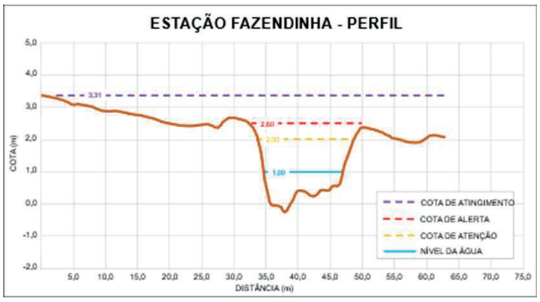
For comparison purposes, the following criterion was used as a basis: Good (30% of the flow recommended).

This range is considered by many authors to be sufficient to maintain levels suitable for survival (BENNETI & LANNA, 2003), where habitat reduction is not so considerable (REIS, 2007). Furthermore, it was used as a sufficiency criterion by ANA in the Ten-Year Plan (2004-2013) for Water Resources of the São Francisco River Basin (SARMENTO, 2007).

4.3.3. WET PERIMETER METHOD

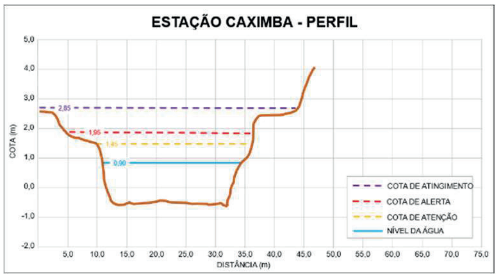
From the survey of the bathymetries of each fluviometric station found in the field records obtained through the ANA National Water Resources Information System (SNIRH) page, the river sections of each fluviometric station were identified as shown in FIGURES 5,6, 7,8 and 9.

FIGURE 5 – RIVER PROFILE SECTION - FAZENDINHA STATION



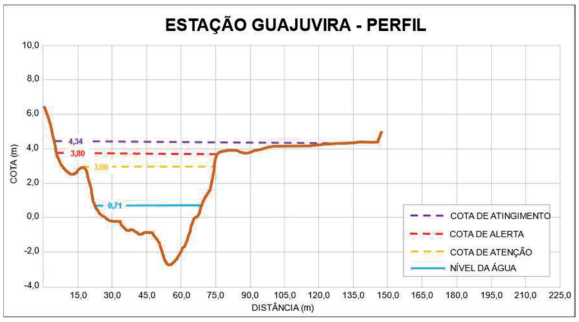
SOURCE: The author (2023).

FIGURE 6 – RIVER PROFILE SECTION - CAXIMBA STATION



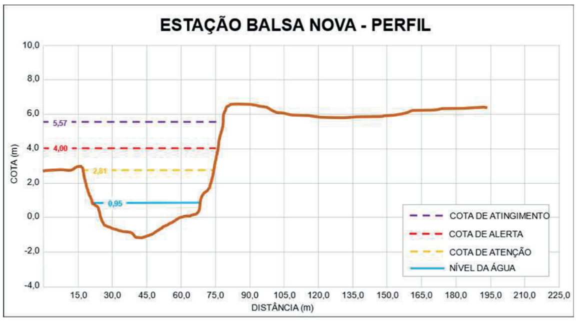
SOURCE: The author (2023).

FIGURE 7 – RIVER PROFILE SECTION - GUAJUVIRA STATION



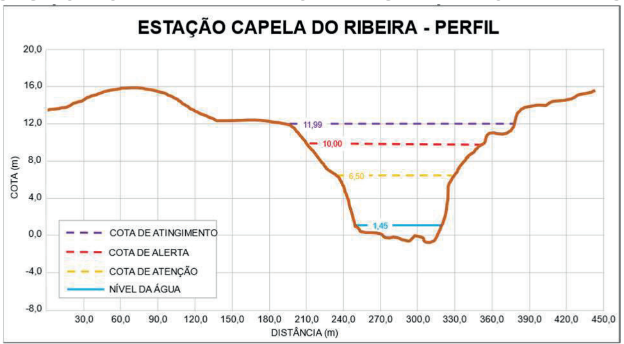
SOURCE: The author (2023).

FIGURE 8 – RIVER PROFILE SECTION - NOVA FERRY STATION



SOURCE: The author (2023).

FIGURE 9 – SECTION OF THE RIVER PROFILE - CAPELA DO RIBEIRA STATION



SOURCE: The author (2023).

RCMOS – Multidisciplinary Scientific Journal O Saber.
ISSN: 2675-9128. Sao Paulo-SP.

The sections were drawn in AutoCad and with the help of this software and using heights, wet areas and wet perimeters were identified. Flow rates were calculated using the Manning equation. TABLES TABLE13, TABLE 14,TABLE15,TABLE16and TABLE17present the values obtained for the perimeters and the results of the flow calculations for each section of each Station.

TABLE 13 – STATION OBTAINED VALUES LITTLE FARM

PERIMETER (m)	FLOW RATE (m³/s)
13.2	11,919
8.1	0.944
7.3	0.790
3.4	0.122

SOURCE: The author (2023)

TABLE 14 – VALUES OBTAINED PONTE DA CAXIMBA

PERIMETER (m)	FLOW RATE (m³/s)
24.42	73.56
22.95	44.16
21.87	20.90
20.58	5.18

SOURCE: The author (2023)

TABLE 15 – STATION OBTAINED VALUES GUAJUVIRA

PERIMETER (m)	FLOW RATE (m³/s)
47.77	241.75
45.04	110.00
25.31	50.21
9.18	4.82

SOURCE: The author (2023).

TABLE 16 – STATION OBTAINED VALUES FERRY NEW

PERIMETER (m)	FLOW RATE (m³/s)
207.6	47.37
105.3	47.61
58.44	36.67
11.31	27.13

SOURCE: The author (2023).

TABLE 17– VALUES OBTAINED FROM CAPELA D STATION THE RIBEIRA

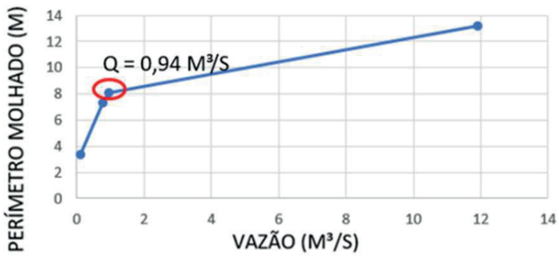
PERIMETER (m)	FLOW RATE (m³/s)
70.10	202.34
64.47	93.99
59.14	37.90
9.60	0.81

SOURCE: The author (2023).

The graphs are defined relating the wetted perimeter with the flow rate, they are

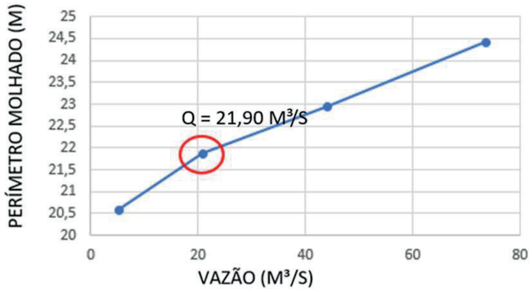
The inflection points for each of the fluviometric station curves were identified. FIGURES FIGURE10,FIGURE11,FIGURE12,FIGURE13and FIGURE14present the inflection point for each of the fluviometric stations, and TABLE 18 presents the flow rates references found establishing the relationship between the flow rate and the wetted perimeter determined by the method.

FIGURE 10 – FAZENDINHA STATION TURNING POINT



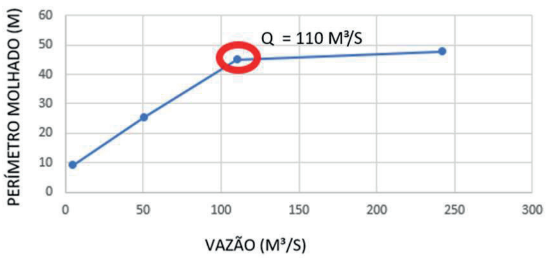
SOURCE: The author (2023).

FIGURE 11 – INFLECTION POINT AT CAXIMBA PONTE STATION



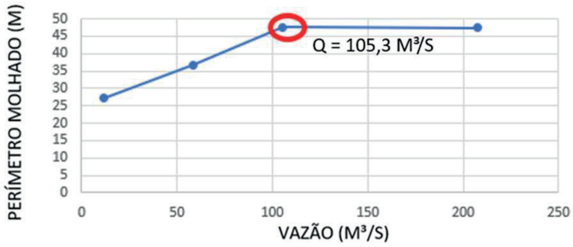
SOURCE: The author (2023).

FIGURE 12 – TURNING POINT GUAJUVIRA STATION



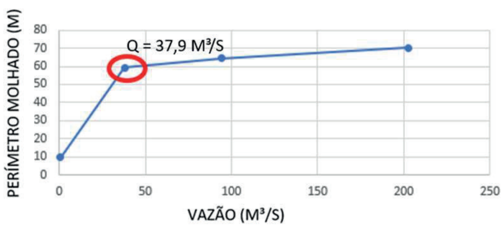
SOURCE: The author (2023).

FIGURE 13 – INFLECTION POINT OF BALSA NOVA STATION



SOURCE: The author (2023).

FIGURE 14 – INFLECTION POINT CAPELA DO RIBEIRA STATION



SOURCE: The author (2023).

TABLE 18 REFERENCE FLOW VALUES DEFINED BY THE PERIMETER METHOD WET

MONITORED STATIONS NAME	REFERENCE FLOW FLOWS DETERMINED BY THE METHOD OF WET PERIMETER (m^3/s)
LITTLE FARM	0.94
CAXIMBA BRIDGE	21.90
GUAJUVIRA	110.0
FERRY NEW	105.3
RIBEIRA CHAPEL	37.9

SOURCE: The author (2023).

4.3.4. Comparison between the methodology used in Paraná and the study methodologies

The comparisons between the reference flows used in Paraná and the reference flows of the methods used are presented in TABLE 19.

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ISSN: 2675-9128. Sao Paulo-SP.

TABLE 19 – REFERENCE FLOW FLOWS OF FLOW METER STATIONS USED IN THE STATE OF PARANÁ COMPARED WITH FLOW FLOWS METHODS STUDIED

MONITORED STATIONS		MINIMUM FLOW OF REFERENCE (m^3/s)	FLOW REGIME CALCULATED , (m^3/s)	FLOW REGIME RECOMMENDED BY TENNANT METHOD (m^3/s)		FLOW REGIME CALCULATED BY PERIMETER METHOD WET (m^3/s)
NAME	**CODE**	**50%** %	**50%** , (m^3/s)	**MAY - OCTOBER (DRY)**	**NOVEMBER - APRIL (RAINY)**	**PERIMETER METHOD WET(M^3/S)**
LITTLE FARM	65010000	0.38	0.29	0.56	1.12	0.94
CAXIMBA BRIDGE	65019700	0.20	0.18	1.12	2.23	21.90
GUAJUVIRA	65025000	6.35	4.24	10.47	20.94	110.0
FERRY NEW	65028000	9.06	5.60	29.63	59.25	105.3
RIBEIRA CHAPEL	81200000	24.03	20.1	23.38	46.76	37.9

SOURCE: The author (2023).

In the comparative analysis the �,��, using for comparison the value of 50% of the flow �,��it was found that the results would be more restrictive to those used by Paraná state legislation. Results using the Tennant methodology (considering the Good range of the Tennant Method, the range is considered by many authors to be sufficient to maintain adequate levels of survival (BENNETI & LANNA, 2003)) and the Wet Perimeter method demonstrates that the values obtained were higher than those required by state legislation of Paraná.

5. CONCLUSIONS AND FUTURE WORK

With the aim of ensuring water security and promoting sustainable management of water resources, it is essential to carefully analyze the system and adopt appropriate measures to guarantee access to water for all those who depend on it, especially during periods of water scarcity. Consequently, it is important to evaluate public policies and adaptation measures to minimize water vulnerability in response to possible climate changes. Finally, the relevance of analyzing future water supply scenarios stands out, allowing managers to incorporate proposals for sustainable development.

The minimum reference flow is a fundamental parameter for the management of water resources, being used as a standard to guarantee the preservation of aquatic and terrestrial ecosystems associated with a given watercourse.

Data from the historical flow series from the five fluviometric stations: Fazendinha, Ponte da Caximba, Guajuvira, Balsa Nova and Capela do Ribeira; stations in the Alto Iguaçu and Ribeira river basins, in the state of Paraná, were exported from ANA's SNIRH. And based on this data, the minimum reference flow for each station was calculated using **50%** %,methodology currently adopted by the state of Paraná.

Paraná's methodology for calculating the minimum reference flow is based on the use of ��%. To determine the minimum reference flow, the Paraná methodology uses 50% of the ��%, which is a value considered safe and adequate to maintain adequate ecological and water conditions in a river basin.

To compare the reference flows used in the state of Paraná, we used the flows from the historical series from the same fluviometric stations to calculate the reference flows using three different methodologies:

- Methodology �,��: to find the minimum reference flow rate, the parameter of Ordinance No. 20/99 – SUDERHSA (DOE OF 06/16/99) which brings the maximum grantable limit of 50% of the �,��.

- Tennant methodology: to find the minimum reference flow rate, the range "Good" which is calculated at 30% of the recommended flow;

- Wet Perimeter Method: processes that use hydraulic parameters to estimate flow are based on simple relationships between hydraulic variables and channel geometry. Although these methods require field data, such as measurements of depth and speed, they allow establishing a relationship between the wetted perimeter and the flow. The Manning equation is one of the hydraulic equations used to express this relationship.

To determine the recommended flow rate to maintain suitable habitat conditions, Depth and velocity measurements are performed for at least three different flows. From this data, a graph is constructed that relates the wetted perimeter with the flow rate, identifying the inflection point of the curve. This point is the limit beyond which an increase in flow results in an insignificant increase in the wetted perimeter and a rapid deterioration of habitat conditions. The recommended flow at the inflection point is considered the minimum reference flow, that is, the flow that must be maintained to preserve adequate habitat conditions.

Defining the minimum reference flow is an important tool for decision-making in relation to water use permits. There is the possibility of stating that the reference flows of fluviometric stations can be adjusted upwards or downwards.

There is the possibility of increasing the minimum reference flow of these stations in rainier seasons, as demonstrated by the reference flows found by the Tennant method, consequently increasing the water concession at these stations so that users can use the available water more efficiently. And in periods of drought there is the possibility of restricting the reference flows, as found with the application of the method �,��,ensuring the minimum flow in the water body and consequently reducing the water concession at these stations. The minimum reference flow is not necessarily the minimum flow of a water body, but rather the minimum flow that must be maintained to guarantee the preservation of the ecosystems that depend on it and the guarantee of water availability for users located downstream of the point under analysis. .

The methods analyzed in this work - ��%, Tennant, �,��and Wet Perimeter - showed minimum values for reference flows in a quantitative context, that is, without considering the implications for water quality in the case of multiple uses, if this flow were used as a reference. However, it is essential to adopt a more comprehensive methodology that takes into account not only the quantity, but also the quality of water, to establish acceptable values for granting.

The discrepancy in flow values obtained using the Wet Perimeter method is notable. Furthermore, the minimum reference flow value varies considerably between different sections. The biggest challenge in using the Wet Perimeter method is determining the appropriate number of bathymetric sections and obtain them. Relying on just one or a few sections is not sufficient to produce a reliable estimate of the minimum reference flow. This also means that it is not appropriate to focus on just one section of the river, as there are migratory species that may be at risk of extinction if they are unable to move along the river's course. As an alternative, it is recommended to use the IFIM Method, which has been extensively studied and has technical data available in the areas of biology, geotechnics and engineering. IFIM can also be used to validate or refute the Wet Perimeter method. In Portugal (2002), the initial use of the Wet Perimeter Method is suggested during the preliminary study phase, until adequate data is obtained for the use of the IFIM Method, as it adds considerable information to complement the Wet Perimeter method.

When designing new experiments, it is recommended to determine the minimum flow rate of reference using the IFIM methodology (Incremental Methodology for Flow in Streams) so that it can be compared with the methodologies used in this study.

The Instream Flow Incremental Methodology (IFIM) was developed by the “Cooperative Instream Flow Service Group”, currently “Aquatic Systems Branch of the National Ecology Research Center”, USFWS, in Fort Collins, USA, for solving problems regarding the management of water resources that involve the implementation of any type of hydraulic project in rivers, aiming to reduce the negative impact caused to ecosystems (Bovee, et al., 1998).

IFIM is composed of several theoretical and computational procedures that are interconnected to describe the temporal and spatial characteristics of river habitat in response to changes in the fluviometric regime of rivers.

This method is classified as a habitat methodology, and its application to fluviometric stations studied would add to the comparison an approach that takes into account habitat use to evaluate the relationship between flow and the availability of physical habitat for the species analyzed. Furthermore, IFIM incorporates variable or multiple rules that can be used in flow-based negotiations to meet the needs of the aquatic ecosystem, considering demands for water supply and other uses.

The applicability of this study may extend to data from other stations fluviometric measurements of both the state of Paraná and any other state. If there is interest in comparing it with the methodology adopted by other state granting bodies, it is essential to examine the methodology used by the respective body

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