Comparison of two methods for determining $Q_{95}$ reference flow in the mouth of the surface catchment basin of the Meia Ponte river, state of Goiás, Brazil

Abstract: The preferred data for analyzing water availability are those of historical flow series of the sources of interest; however, most Brazilian watersheds do not have sufficient fluviometric monitoring. Such cases require techniques for transposing data from one region to another, otherwise known as ‘flow regionalization’. The present work aimed to compare the method proposed by Secretaria de Meio Ambiente e Desenvolvimento Sustentável (SEMAD) of the state of Goiás with the traditional method of regionalization for determining reference flow at the mouth of the surface catchment basin of the Meia Ponte river. Data from eight fluviometric stations were used for regionalization, with the regression equations being adjusted using four different models. The result revealed that the potential and linear models performed the best, both with $R^2$ and $R^2_a$ values of 0.996 and 0.995, respectively. The relative error in the application of the potential model and of the method adopted by SEMAD were below 30%. The reference flows obtained by the two best performing methods differed, with flow determined by the traditional method being 5.93% lower than that of the SEMAD equation. Therefore, a more detailed study is recommended to determine which equation models better fit the region.

Keywords: Ecological flow, Regionalization, Water resources

1 Introduction

According to Brazilian Federal Law no 9.433 of 08 January 1997 [1], also called Lei das Águas (Law of the Waters), to ensure the availability of water for current and future generations, management of water resources must provide for multiple uses and should be decentralized, with participation of all stakeholders, from the government to the community. Given these fundamentals of the main Brazilian legislation in force for over twenty years, the importance of studying the constituents of water resources management, such as watersheds, is clear. Various aspects of these territorial units must be characterized, such as: contribution area, main river and its tributaries, planning, slope, rainfall regime, land use and occupation, climate and flow. This last characteristic is certainly the most relevant, and poses important questions, including: What is the water availability of a given basin? How much water can be reserved? How much water should be kept in water sources to maintain ecosystems? These, among other questions, can only be answered after analysis of the flow present in a basin, which, depending on the purpose of the study, can be maximum flow, minimum flow, permanence flow and/or long-term average flow.

For the analysis of water availability, it is, according to Fioreze et al. (2008) [2], preferable to use data from historical series of flows of the sources of interest. For most Brazilian watersheds, however, sufficient fluviometric monitoring is lacking. Such cases, therefore, require techniques for transposing data from one region to another. This method, called ‘flow regionalization’, exploits...
the maximum amount of hydrological information available to estimate values in locations without data or with other faults [3].

According to Wolff et al. (2014) [4], two of the most used methodologies for flow regionalization stand out: application of regression equations to hydrologically homogeneous regions, and automatic extrapolation in an information systems environment. Considering the available options, it is necessary to analyze which methodology is viable for any particular study.

In addition to regionalization methods, it is important to determine which flow is to be studied. According to Silva et al. (2015) [5], such calculated values are also used as reference flows for granting use privileges by water resource management bodies, which directly influence total water available for withdrawal.

Brazilian states generally adopt different flows in their studies for granting use privileges, taking into account local reality and the hydrological and climatic characteristics of each location. According to Santos et al. (2006) [6], the states of Bahia, Ceará and Distrito Federal, adopt $Q_{90}$, which means that the flow is present 90% of the time, while the other 10% of the time the flow is not met. In contrast, the states of Paraná, Minas Gerais and Rio de Janeiro work with $Q_{210}$, the minimum flow present during seven consecutive days with the time of ten years of return.

For studies of water availability in the state of Goiás, Resolution n° 09/2005 of Conselho Estadual dos Recursos Hídricos (CERH) [7] determines that the flow adopted as a reference for granting water use privileges is the flow that guarantees permanence 95% of the time ($Q_{95}$), that according to Bazzo (2017) [8] is the flow that equals or exceeds in 95% of the time, that is, 5% of the time the flow present in the river will be less than $Q_{95}$. However, Instrução Normativa (IN) n° 04/2015 of Secretaria de Meio Ambiente e Desenvolvimento Sustentável (SEMA) of Goiás [9] determines that for the calculation of water availability, the specific reference flows ($Q_{95}$ specifically) previously defined IN must be adopted.

In view of the above, and with the purpose of expanding scientific research on water resources and important hydrological variables for the management of water resources in the state of Goiás, the present work aimed to compare the traditional method of flow regionalization with the method used by SEMAD, to determine which method best determines reference flow ($Q_{95}$) at the mouth of the surface catchment basin (SCB) of the Meia Ponte river.

## 2 Methods

The state of Goiás, encompassing 340,111,78 km² in the Center-West Region of Brazil, contains 246 municipalities and has a population of 6,434,048 inhabitants [10]. The Meia Ponte river watershed is located in the south-central region of the state and is one of the most important basins in Goiás as it covers about 12,180 km² or 4% of its territory, while the river itself is the main water source for the population of Goiânia, the state capital.

The study area of the present work is the surface catchment basin (SCB) located in the upper part of the Meia Ponte river watershed (Figure 1). It encompasses an area of 1,633.23 km² in 10 municipalities: Itauçu, Inhumas, Ouro Verde de Goiás, Goianira, Brazabrantes, Nova Veneza, Damolândia, Nerópolis, Santo Antônio de Goiás and a small part of Goiânia.

A methodology involving three stages was employed to compare reference flows, which in the state of Goiás are represented by $Q_{95}$. The first stage consisted of conducting a flow regionalization study, for which fluvimetric data were obtained from eight stations located throughout the Meia Ponte river watershed (Figure 1), by means of accessing the HIDROWEB platform of Agência Nacional de Águas (ANA; National Water Agency). The regionalization method applied was that proposed by ELETROBRÁS (1985a) [11], and here called the Traditional Method. The main characteristic of the Traditional Method is the application of regression equations to obtain the flow in any part of the drainage of the basin under study [12].

Pre-processing of the data was thusly carried out using SisCAH 1.0 software to select periods in common among stations with continuous data (i.e. no failures at any of the stations). Therefore, historical series between 32 and 34 years old were used and a hydrological year of September to August was adopted due to the climatic characteristics of the region. The data period used for all stations was between 1980 and 2014, with the exception of station 60680000, for which the period of between 1980 and 2012 was adopted due to the availability of data specifically from its fluvimeter. Since the $Q_{95}$ for a given season does not depend on the $Q_{95}$ of others, there is no problem adopting this period with a two-year difference in the data.

It is important to note that of the 13 existing stations in the Meia Ponte river watershed, it was possible to use the historical series could only be used for eight since no data records were found in the HIDROWEB database for the other stations.

With the $Q_{95}$ values and the respective areas of each fluvimetric station within the same watershed, it was
possible to apply regression models with the dependent variable being the reference flow present 95% of the time ($Q_{95}$) and the independent variable being the area of contribution of the fluviometric stations. The equations were obtained using SisCORV 1.0 software and adjusted using five different regression models: linear model, potential model, exponential model, logarithmic model and reciprocal model, according to Equations 1, 2, 3, 4 and 5 [2, 12, 13].

- Potential Model:
  $$Q = \beta_0 X_1^{\beta_1} X_2^{\beta_2} \ldots X_m^{\beta_n}$$  

- Linear Model:
  $$Q = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_m$$  

- Exponential Model:
  $$Q = e^{\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_m}$$  

- Logarithmic Model:
  $$Q = \beta_0 + \beta_1 \ln X_1 + \beta_2 \ln X_2 + \ldots + \beta_n \ln X_m$$  

- Reciprocal Model:
  $$Q = (\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_m)^{-1}$$

The second stage consisted of estimating reference flows using the previously found regression equations and the methodology indicated by SEMAD of Goiás in its Manual Técnico de Outorga [14]. The procedure used by SEMAD consists of determining reference flow through the product of the specific $Q_{95}$, which for the Meia Ponte river water-
shed is 4.32 L/km², and the contribution area upstream of the point of interest, according to Equation 6.

\[ Q_{95} = Q_{95\text{spe}} \times DA \]  

(6)

Where:
\( Q_{95} \) = flow present 95% of the time (L/s);
\( Q_{95\text{spe}} \) = specific flow (L/s/km²);
\( DA \) = drainage area (km²).

Finally, the third stage evaluated the precision of the method used by SEMAD and of the regression models proposed herein using the relative error (RE) between observed and estimated flows [15], which is given by Equation 7.

\[ RE = 100 \times \frac{Q_{\text{obs}} - Q_{\text{est}}}{Q_{\text{obs}}} \]  

(7)

Where:
\( RE \) = relative error (%);
\( Q_{\text{obs}} \) = observed flow obtained from the analysis of the historical series at fluviometric station (m³/s);
\( Q_{\text{est}} \) = estimated flow based on regionalization methodologies (m³/s).

As described by ELETROBRÁS (1985b) [16], RE values of less than 30% are considered acceptable, and can be presented in a negative way, indicating overestimation of flow, or in a positive way, indicating underestimation of flow. The method with the best performance was selected by taking into account the regression equation that presented the highest coefficient of determination \( R^2 \) and \( R^2_a \) and the lowest relative RE between observed and estimated flows[12].

### 3 Results and Discussion

#### 3.1 Regression equations obtained by the Traditional Method

Table 1 shows the drainage areas and \( Q_{95} \) values for the eight fluviometric stations used in the regionalization study.

As can be seen in Table 1, the contribution areas for the fluviometers ranged from 51 to 11,527 km², and so it is important to note that the generated regionalization equation should not be applied to areas that require extrapolation above or below this range. According to Silveira et al. (1998) [17], the technique should not be applied outside the limits established by regional equations and especially for basins with areas smaller than 100 km², because the mechanism for transforming rain into flow occurs differently in small basins since they have very specific physical characteristics.

SisCAH 1.0 software was used to obtain flow rates present 95% of the time for all stations, which ranged 0.257 – 41.824 m³/s. Using these values, and their respective contribution areas, Equations 8, 9, 10, 11 and 12 were obtained, which are the regression models for estimating \( Q_{95} \) in the Meia Ponte river watershed.

- Potential Model:
  \[ Q_{95} = 0.0006 \times A^{0.9478} \]  
  (8)

- Linear Model:
  \[ Q_{95} = 0.665 + (A \times 0.0036) \]  
  (9)

- Exponential Model:
  \[ Q_{95} = 2.179 \times 2.718^A \times 0.00029 \]  
  (10)

- Logarithmic Model:
  \[ Q_{95} = 37.243 + (6.713 \times \ln A) \]  
  (11)

- Reciprocal Model:
  \[ Q_{95} = (0.951 + (A \times -0.000115))^3 \]  
  (12)

Table 2 shows the results obtained for the coefficients of determination \( R^2 \) and \( R^2_a \), as well as the standard error of the proposed models.

The results reveal that the potential and linear models had the best performance, with \( R^2 \) and \( R^2_a \) of 0.996 and 0.995, respectively. However, the standard error for the potential model was about ten times smaller than that of the linear model. The potential model had an adjusted coefficient of determination \( R^2_a \) of 0.99, which indicates that the proposed equation model is quite explanatory and fits the data well. Thus, the dependent variable, in this case a \( Q_{95} \), is satisfactorily explained by this regression equation.

The exponential, logarithmic and reciprocal models had low values of \( R^2 \) and \( R^2_a \), revealing them to be of low performance. A classification range for the coefficient of determination could not be found, but it is known that values closer to 1 indicate better models. This is because, according Naghettini & Pinto (2007) [18], in short, \( R^2 \) represents how much of the variability of the studied function a model can explain.

To compliment the analysis of the proposed models, Figure 2 presents the results of the estimated flows for each station in relation to observed flows. The linear and potential models obtained estimated values closer to the true values, while the others presented discrepant values and so their use is not recommended for estimating flow in this case.
Comparison of two methods for determining $Q_{95}$ reference flow in the mouth

Table 1: Information on the fluviometric stations used.

| ID  | Station     | Station name          | Observed period | Contribution area (km$^2$) | $Q_{95}$ observed (m$^3$/s) |
|-----|-------------|-----------------------|------------------|---------------------------|-----------------------------|
| 1   | 60680000    | Ponte Meia Ponte      | 1980 - 2012      | 11,527                    | 41.824                      |
| 2   | 60665000    | Professor Jamil       | 1980 - 2014      | 1,198                     | 4.767                       |
| 3   | 60654000    | Fazenda Sucuri        | 1980 - 2014      | 1,265                     | 6.008                       |
| 4   | 60650000    | Jusante de Goiânia    | 1980 - 2014      | 2,970                     | 13.146                      |
| 5   | 60640000    | Montante de Goiânia   | 1980 - 2014      | 1,798                     | 6.435                       |
| 6   | 60642000    | Captação João Leite   | 1980 - 2014      | 781                       | 3.267                       |
| 7   | 60653000    | Ribeirão das Caldas   | 1980 - 2014      | 51                        | 0.257                       |
| 8   | 60635000    | Inhumas               | 1980 - 2014      | 568                       | 2.243                       |

Figure 2: Observed flows and flows estimated by the studied models.

Table 2: Values of $R^2$, $R^2_a$ and standard error.

| Model      | $R^2$  | $R^2_a$ | Standard error |
|------------|--------|---------|----------------|
| Potential  | 0.996  | 0.995   | 0.099          |
| Linear     | 0.996  | 0.995   | 0.921          |
| Exponential| 0.561  | 0.488   | 1.051          |
| Logarithmic| 0.590  | 0.522   | 9.342          |
| Reciprocal | 0.109  | -0.039  | 1.338          |

3.2 Relative error (RE)

To assess the accuracy of the methods, the RE between the observed and estimated values was calculated according to Moreira & Silva (2014) [15]. Table 3 shows the RE values, which were calculated for the two models that had the best performance — linear and potential — and for the model used by SEMAD.

The REs calculated from the flow estimates obtained by the Traditional Method using the potential model were between $-13.34$ and 12.98%, at stations 5 and 3, respectively. The REs calculated from the flow estimates obtained by the Traditional Method using the linear model were between $-230.19$ and 13.61%, at stations 7 and 4, respectively. The REs calculated from the flow estimates obtained by the SEMAD method were between $-20.70$ and 14.27%, at stations 5 and 7, respectively.

The linear model had higher RE values than the others, however, only at station 7, Ribeirão das Caldas, was a there a value above 30%, which is considered unacceptable by the method applied. This station had an overestimated flow of more than 200%, however, it has a contribution area of 51 km$^2$, making it the smallest area for the set of analyzed stations. According to Junior et al. (2003) [19], there are several limitations that generate uncertainties in results for smaller watersheds. According to Silveira et al.
Table 3: Percent relative error (ER) and $Q_{95}$ values in m$^3$/s, obtained from the analysis of historical series and estimated by different methods of flow regionalization.

| ID   | Station       | Station name          | $Q_{95}^{\text{obs}}$ | $Q_{95}^{\text{est}}$ | RE(%)  | $Q_{95}^{\text{est}}$ | RE(%)  | $Q_{95}^{\text{est}}$ | RE(%)  |
|------|---------------|-----------------------|-----------------------|-----------------------|--------|-----------------------|--------|-----------------------|--------|
| 1    | 60680000      | Ponte Meia Ponte      | 41.824                | 42.447                | -1.489 | 42.162                | -0.809 | 49.797                | 19.062 |
| 2    | 60665000      | Professor Jamil       | 4.767                 | 4.965                 | -4.152 | 4.978                 | -4.422 | 5.175                 | -8.566 |
| 3    | 60654000      | Fazenda Sucuri        | 6.008                 | 5.228                 | 12.987 | 5.219                 | 13.132 | 5.465                 | 9.041  |
| 4    | 60650000      | Jusante de Goiânia    | 13.146                | 11.739                | 10.703 | 11.357                | 13.609 | 12.830                | 2.401  |
| 5    | 60640000      | Montante de Goiânia   | 6.435                 | 7.295                 | -13.368| 7.138                 | -10.922| 7.767                 | -20.705|
| 6    | 60642000      | Captação João Leite   | 3.267                 | 3.310                 | -1.311 | 3.477                 | -6.416 | 3.374                 | -3.273 |
| 7    | 60653000      | Ribeirão das Caldas   | 0.257                 | 0.249                 | 3.026  | 0.849                 | -230.195| 0.220                 | 14.272 |
| 8    | 60635000      | Inhumas               | 2.243                 | 2.447                 | -9.117 | 2.710                 | -20.811| 2.454                 | -9.396 |

Figure 3: Relative errors (REs) for the application of the potential model and the method used by SEMAD to estimate $Q_{95}$ at the eight studied fluvimetric stations.

(1998) [17], this happens because as basin area decreases the scale of detailing is reduced, which makes it difficult to characterize homogeneous regions.

The results for RE are provided in Figure 3 and show that the application of the potential model and the method adopted by SEMAD had values below 30%. In general, the potential model had estimated values closer to the observed, demonstrating better performance. This model has been widely used in the literature and has performed better when compared to others, as observed in the study of Ribeiro et al. (2005) [12], which compared flow regionalization methodologies for the Doce river basin and obtained the best performance with potential-type regression equations with an average RE of 16.56%. Fioreze et al. (2008) [2] evaluated the performance of flow regionalization equations for the Santa Bárbara river basin, with potential-type regression equations showing good performance for estimating $Q_{95}$ with satisfactory REs. However, the use of the method proposed by SEMAD was not ruled out since the results were also satisfactory, even though the RE values were higher.

3.3 Flow estimation at the mouth of the SCB of the Meia Ponte river basin

The equation indicated by SEMAD and the potential-type regularization equation were used to estimate the reference flow values present 95% of the time at the mouth of the SCB and are shown in Table 4. The regularization equation had a 5.93% lower flow than that of the SEMAD equation. It is noteworthy that without the possibility of applying other techniques, the use of the lowest estimate creates more security for a manager when it comes to granting water rights.

The equation indicated by SEMAD of Goiás uses specific flow as a reference, which for the Meia Ponte river and its tributaries is 4.32 L/s.km$^2$. This information was obtained from the Plano de Recursos Hídricos da Bacia do
Table 4: Estimated $Q_{95}$.

| Equation                                                                 | $Q_{95}$ (L/s) |
|-------------------------------------------------------------------------|----------------|
| $Q_{95} = 0.0006^* (A^{0.9478})$ Indicated by SEMAD                     | 7055.55        |
| Proposed regionalization equation                                        | 6660.05        |

The Meia Ponte river watershed is over 11 thousand km$^2$ and its specific flow varies throughout the basin.

The regionalization equation for flow was obtained by analyzing eight fluvimetric stations present in the Meia Ponte river watershed, with historical series of 32 and 34 years old, which better describes the hydrological behavior in the region than the SEMAD equation. However, both methods use the contribution area of the fluvimeters to explain $Q_{95}$, and analysis of the results for flow estimates reveals that the values are on the same order of magnitude, with a difference of 5.93%.

In this case, the potential-type regression equation is recommended for use since the coefficients of determination were satisfactory and the RE was lower than that for the SEMAD equation. Nonetheless, due to the differences found in the results, adopting both flow monitoring techniques at the mouth of the SCB for a period of time is recommended, so that comparisons can be made between the observed and estimated data and a study of the performance of the two methods can be further developed.

It is important to note that such studies are of great relevance for the management of water resources, especially with regard to the granting of water rights. It is also noteworthy that this is a geographically and economically important region for the State and needs management of its water resources to avoid new conflicts over water use and maintaining the balance of the environmental system of the water sources.

### 4 Conclusions

It can be concluded that, based on the analyzed parameters, the potential model had the best performance of the four models analyzed using the Traditional Method. Comparing the potential model with the method used by SEMAD revealed it to have a lower RE, with estimated flows closer to the observed. The reference flows at the mouth of the SCB of the Meia Ponte river obtained by the best performing methods differed, with the flow determined by the Traditional Method being 5.93% lower than that of the equation of SEMAD of Goiás.

The reference flows found here are on the same order of magnitude, however, their difference becomes relevant when it comes to water availability. Therefore, in order to support decision-making based on technical analysis, a more detailed study should be carried out that includes flow measurement at the mouth of the watershed and comparisons with other flow regionalization methods in order to determine which equation models best fit the region.

### Acknowledgement

Thanks go to Pós-Graduação em Ciências Ambientais de Universidade Federal de Goiás and Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), for funding the research.

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