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DETERMINATION OF IDF CURVE: COMPARATIVE STUDY BETWEEN THE BELL METHOD AND RAINFALL EQUATION IN THE CITY OF BREVES, PARÁ

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Abstract. Urban drainage systems are often planned and designed using rainfall intensity equations. These equations allow to estimate the maximum precipitation of heavy rainfall and may be obtained through different methods based on the correlation of a few rainfall data, such as its duration, frequency and distribution. One of those is the Bell's method, used in this paper. However, the lack of pluviograph records as well as short duration data in certain areas have pointed out to the use of pluviometry registers and statistical models as alternatives to assist the design of drainage infrastructure. This paper aims to investigate and compare the performances of the Bell's method and the rainfall equation proposed by Souza et al. (2012) for the city of Breves, in the State of Pará, Brazil. The study was carried out mostly by the processing of rainfall data repositories of three meteorological stations situated in Breves using periods of observation of 8, 11 and 26 years and its statistical analysis. The results obtained showed that the Bell methodology and the intense rainfall equation for the estimation of maximum rainfall with small return periods is applicable and consistent, considering the use of a large data series.

Keywords: IDF Curves, Bell Method, Equation of heavy rains, Breves

1 Introduction

In order to overcome extreme rainfall events, which are often responsible for causing flooding in urban areas and water erosion in rural areas, it's necessary to correctly design and place minor and major drainage systems. The provision of hydro-meteorological data from the place of interest is, thereby, an essential asset to ensure the sizing's accordance to each case's demands.

Conventionally, an urban drainage infrastructure's design is based on a previously defined design rainfall, by which the flow rate to be adopted is estimated. To ensure its optimization, the project is carried out considering the region's intense rains. An intense rainfall is distinguished by its heavy continuous precipitation and short duration and this meteorological phenomenon might trigger off the increasing of flows and consequentially exceed the capacity of inappropriately dimensioned drainage systems, leading to disasters that might comprise material and human losses.

According to Arisz and Burrel [1], some approaches commonly used for selecting the value of rainfall in a design are the representation of the statistical distributions of extreme precipitation data through Intensity-Duration-Frequency (IDF) curves, the most severe historic storm event (design storm) and averaged precipitation patterns based on historical precipitation data for a larger area (synthetic design storms). The determination of IDF curve through Bell's methodology [2] and the rainfall intensity equation proposed by Souza et al. [3] are the main focuses of this paper.

Even though literature provides different methods to determine IDF curves, the Bell Method [2] stands out for its ease of application. The mentioned method is widely used in Brazil, e. g. in the studies of Canal [4] for Espírito Santo, in Sousa et al. [5] for Mato Grosso, in Oliveira et al. [6] for Goiás and in Tischer [7] for Roraima. Bell's methodology [2] provides the precipitation depth for a given duration and return period from an intense standard rainfall of 60-minute duration, and two years of return period.

In some places, however, the determination of IDF relations is compromised by the lack of a reliable pluviograph rainfall monitoring network. In these cases, rainfall intensity equations adapted to the place of interest can prove to be useful alternatives do aid the sizing of drainage projects. In their study, Souza et al. [3] adjust intense rainfall equations for 74 pluviometric stations in the state of Pará, north of Brazil.

Even though there are studies of intensity-duration-frequency relations in Pará, they aren't numerous. As rare examples, there are the study carried out by Souza et al. [3], which adjusted rainfall equations for several localities of the state and the study carried out by Company of Research on Mineral Resources (*Companhia de Pesquisa de Recursos Minerais* - CPRM) [8] which stablishes an IDF equation for the city of Itaituba. This scenario corroborates for the necessity of alternative methods, such as the rainfall equations, to aid the sizing of hydraulic structures, especially drainage.

This paper aims to compare the performances of the Bell method [2] and the rainfall equation proposed by Souza et al. [3] for using in minor and major drainage systems' design through statistical processing of historical pluviometric data series from three meteorological stations situated in Breves/PA.

2 Place of study

The study proposed was carried out in the city of Breves (latitude 01°40'56''S, longitude 50°28'49''W, 40m height), located southwest of Marajó Island, on the banks of Paranaú River, in mesoregion of Marajó, Pará, Brazil, shown in Fig. 1. The municipality is pointed out by the last Brazilian Institute of Geography and Statistics' (*Instituto Brasileiro de Geografia e Estatística* - IBGE) [9] census, in 2010, to have a population of 92,860 citizens and a demographic density of about 9,7 habitants per km².

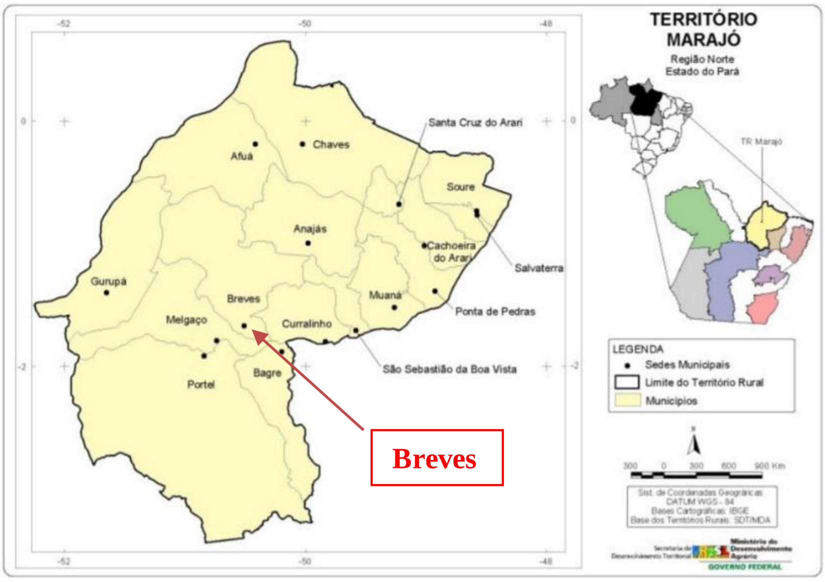

Figure 1. Marajó map, where Breves is located. From: SDT/MDA [10].

The municipality is also said to have only 6,1% of the territory supplied by adequate sewage system and 2,9% and 13,6% of public spaces urbanized and arborized, respectively [9]. These characteristics are of major concern when it comes to urban drainage infrastructure and among with the lack of IDF studies in the city justify its choice for this study.

3 Methodology

Historical rainfall data series from three pluviometric stations located in Breves have been used: *Breves Station* (00150001), *São Miguel dos Macacos Station* (00150002) and *Antônio Lemos Station* (00150003). The stations are currently under supervision of National Institute of Meteorology (*Instituto Nacional de Meteorologia* - INMET), Institute of Economic, Social and Environmental Development of Pará (*Instituto de Desenvolvimento Econômico, Social e Ambiental do Pará* - IDESP) and National Agency of Water (*Agência Nacional de Águas* - ANA), respectively, and the data are available for consultation at ANA's online page.

The periods of analysis used were different for all 3 stations chosen, the same consideration had also been adopted in Garcia et al. [11] and is justifiable since the databases available to use without gaps were not coincident for all of them. According to Mello, Kohls and Oliveira [12], the filling of gaps in a series is not recommended when it comes to extreme data, daily data or when a specific event is analyzed because it might lead to inconsistencies that disqualify the obtained results.

Moreover, considering the hydrological year consisting of 360 days, the years in which there weren't at least this amount of data available had also been discarded for the three historical series studied. The identifications of the stations used, as well as their geographical localization and the periods of observation adopted are presented on Table 1.

Table 1. Pluviometric stations data and their respective periods of observation

Station	Code	Latitude	Longitude	Altitude (m)	Period studied (years)
Breves	0015001	-01°40’48’’	-50°28’41’’	15	1969-1970; 1972-1973; 1980; 1982-1983; 1987
São Miguel dos Macacos	0015002	-01°11’00’’	-50°28’00’’	8	1971-1973; 1975-1982
Antônio Lemos	0015003	-01°47’30’’	-50°26’05’’	Not informed	1986-1990; 1996-2002; 2004-2017

The Bell method [2], to be presented now, provides an alternative to obtain the probable maximum precipitation (PMP), relating it to a certain duration and return period. According to Bertoni and Tucci [13] and Righetto [14], Bell method [2] associates the precipitation depth of an intense rainfall for a given duration and return period to a standard heavy precipitation of 60-minute duration and a 2 year return period. Equation (1) describes the method.

$$h_{(t;Tr)} = \left(\alpha \times \ln\left(Tr+\beta_1\right)\right) \times \left(\beta_2 \times Td^{\gamma} - \beta_3\right) \times h_{(60;2)}. \quad (1)$$

Where $h_{(t;Tr)}$ is the maximum precipitation (mm) for a duration Td and a return period Tr; $h_{(60;2)}$ is the standard maximum precipitation (mm) for a 60-minute duration and 2-year return period; α, β_1, β_2, β_3 and γ are regional parameters adjusted by the least squares method.

According to Oliveira et al. [6], the method is only feasible if either it is possible to estimate $h_{(60;2)}$, which can be done with a few years of pluviographic rainfall data, or by multiplying the precipitation depth ($h_{(1day;2)}$) of one-day duration and two-year return period by a regional factor K, see Eq. (2), in the absence of pluviographic observations, but with data of maximum annual precipitations with one-day duration. The K factor of 0.51, proposed by Righetto [14], has been used.

$$h_{(60;2)} = K \times h_{(1day;2)}. \quad (2)$$

Equation (1) was then adjusted with the parameters proposed by Righetto [14] and based on analysis of pluviometric stations from several continents, described by Garcia et al. [11], acquiring the final form presented in Eq. (3).

$$h_{(t;Tr)} = \left(0.35 \times \ln\left(Tr+0.76\right)\right) \times \left(0.54 \times Td^{0.25} - 0.5\right) \times h_{(60;2)}. \quad (3)$$

Considering that the equation developed by Bell [2] is only applicable to rains of duration between 5 minutes and 2 hours, for return times between 2 and 100 years (Gonçalves [15]), rainfall depths and maximum intensities were determined for the durations of 5, 10, 15, 20, 25, 30, 60 and 120 minutes, and return periods of 5, 10, 25, 50 and 100 years.

Rainfall depths and maximum precipitation intensities (I) have also been calculated for the same durations (Td) and return periods (Tr) by the means of the intense rainfall equation proposed by Souza et al [3], using coefficients determined for the place studied, the municipality of Breves, in Pará, according to Eq. (4).

$$I = \frac{843.3295 \times T_r^{0.0985}}{\left(T_d + 9.7958\right)^{0.7244}}. \quad (4)$$

Where I is the pluviometric intensity, in mm/h; Tr is the return period, in years; Td é the rainfall duration.

In their methodology, Souza et al. [3] used a historical series of pluviometric data with a total of 21 years for the municipality of Breves (PA), which had been obtained through the National Water Agency’s (ANA) database. This information enabled to acknowledge the maximum annual values of daily precipitation and adjust these data to the distribution of Gumbel, which was submitted to the test of Kolmogorov-Smirnov, demonstrating a satisfactory adjustment of the distributions of extreme events of the hydrology to the model.

Finally, a one-day rainfall was broken down into shorter rainfalls based on the methodology proposed by the Department of Water and Electric Power/Environmental Company of São Paulo (*Departamento de Água e Energia Elétrica/ Companhia Ambiental Paulista* - DAEE/CETESB) [16].

The comparison between the two methodologies was then performed using the concordance index proposed by Willmott [17], which is presented in Eq. (5).

$$d=100\left[1-\frac{\sum_{i=1}^{n}(e_i-o_i)^2}{\sum_{i=1}^{n}(|e_i-e_m|+|o_i-o_m|)^2}\right]. \tag{5}$$

Where d is the concordance index, in %; o_i and e_i are the values of the maximum rainfalls estimated by the Bell's method [2] and the intense rains equation, respectively; o_m e e_m are the averages of maximum precipitations estimated by the Bell method [2] and found by the intense rainfall equation [3], respectively.

Camargo and Sentelhas [18] present the interpretation for the results from the Willmott index [17] shown in Table 2, which was also adopted in this study.

Table 2. Interpretation of the Willmott index [17]. Adapted from Camargo and Sentelhas [18].

Concordance Index (d)	Performance
>85%	Excellent
76% a 85%	Very good
66% a 75%	Good
61% a 65%	Regular
51% a 60%	Poor
41% a 50%	Bad
≤40%	Awful

4 Results

The data treatment made it possible to elaborate the IDF curves using the Bell method [2] for the data series of the three pluviometric stations studied: *Antônio Lemos Station* (E_{AL}), *São Miguel dos Macacos Station* (E_{SMM}) and *Breves Station* (E_B). The results are presented in Fig. 2, Fig. 3 and Fig. 4, where I is the pluviometric intensity, in mm/h and Td is the duration considered, in minutes.

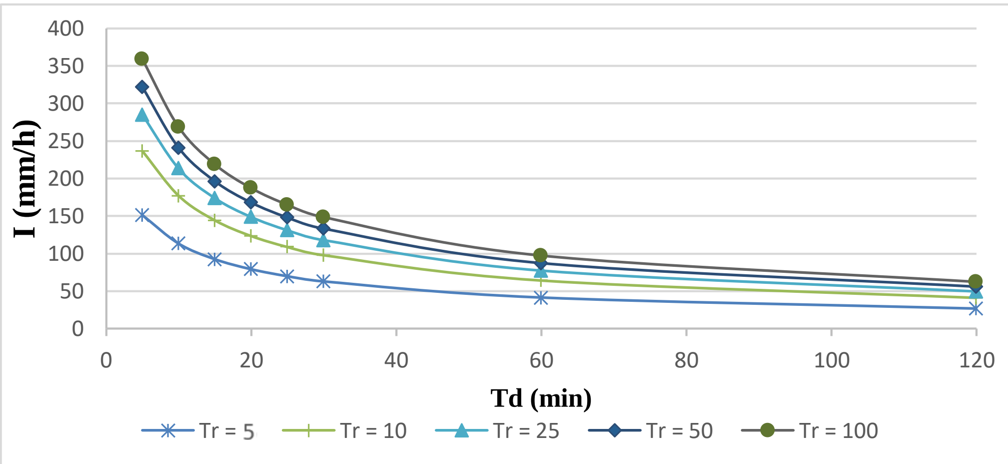

Figure 2. IDF Curve for Breves, considering only *Antônio Lemos Station* ($\boldsymbol{E_{AL}}$)

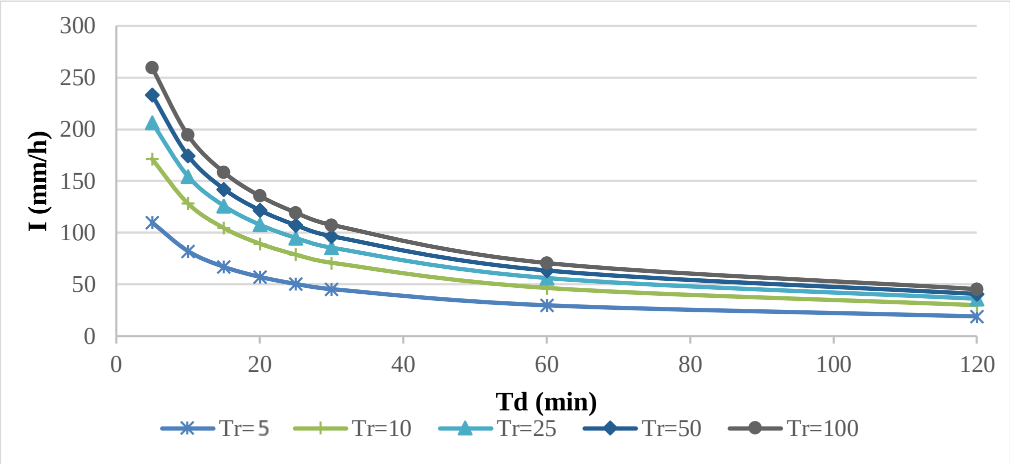

Figure 3. IDF Curve for Breves, considering only *São Miguel dos Macacos Station* ($\boldsymbol{E_{SMM}}$)

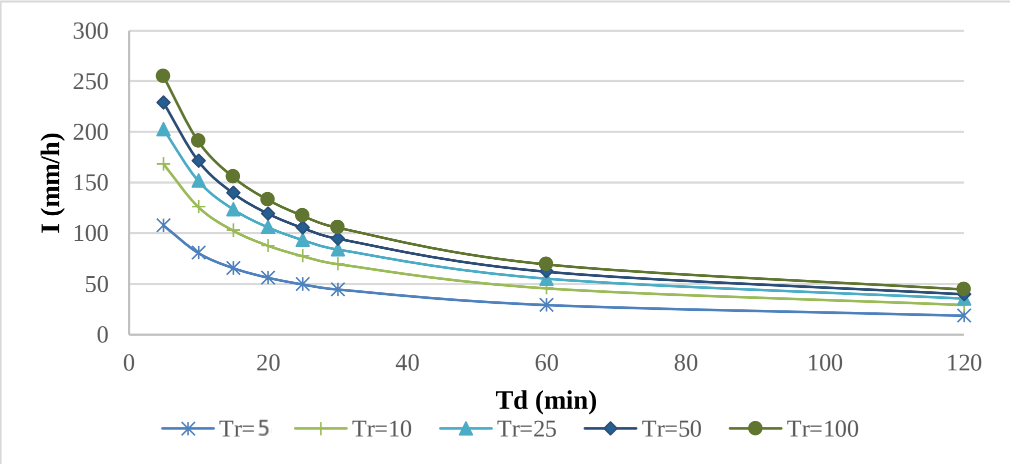

Figure 4. IDF Curve for Breves, considering only *Breves Station* ($\boldsymbol{E_B}$)

The following images present the relation between the probable maximum precipitation (PMP) and their duration (Td) obtained from Bell's methodology [2] (for each of the studied stations) and the intense rain equation provided by Souza et al. [3], considering the previously mentioned return periods of 5, 10, 25, 50 and 100 years for Breves.

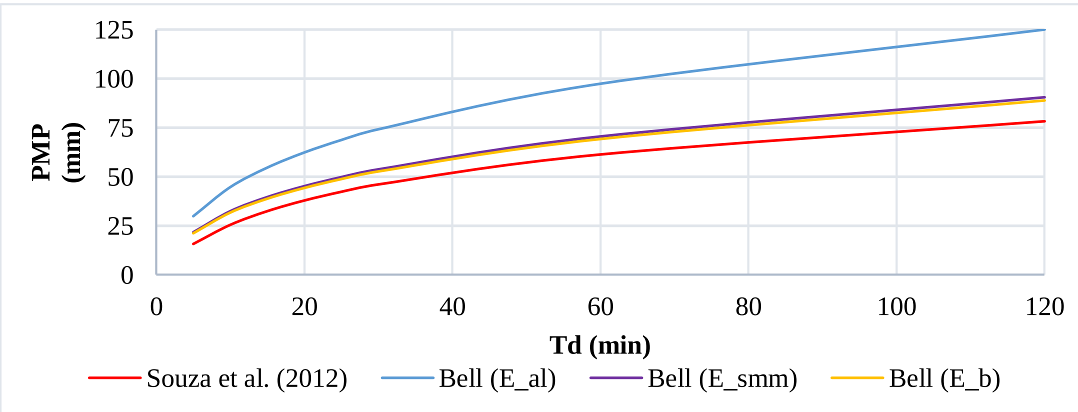

Figure 5. Maximum precipitation estimated for Breves, considering a return period of 100 years

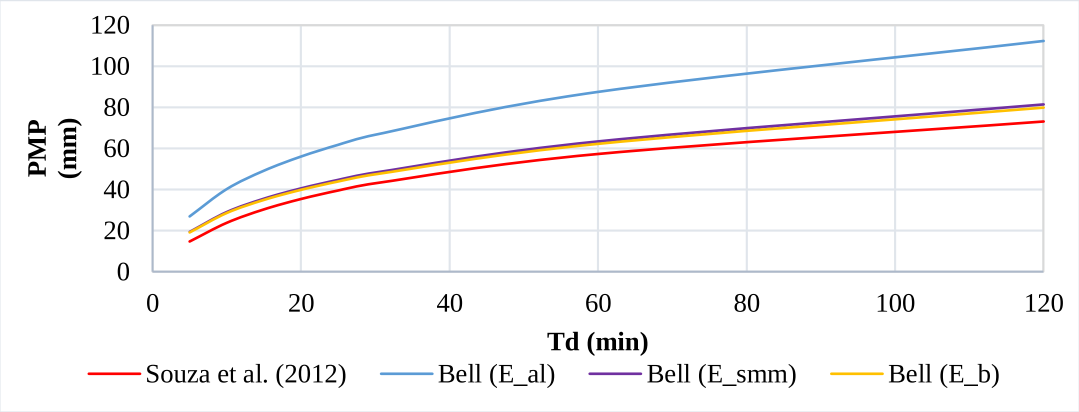

Figure 6. Maximum precipitation estimated for Breves, considering a return period of 50 years

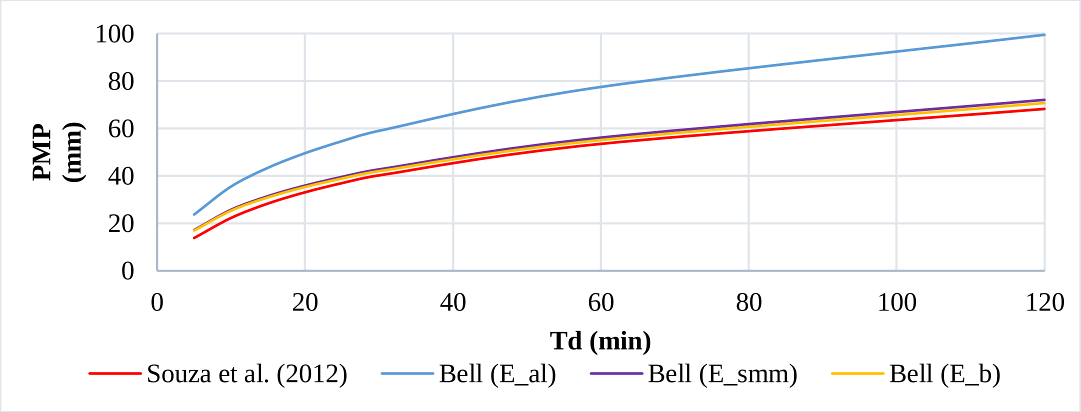

Figure 7. Maximum precipitation estimated for Breves, considering a return period of 25 years

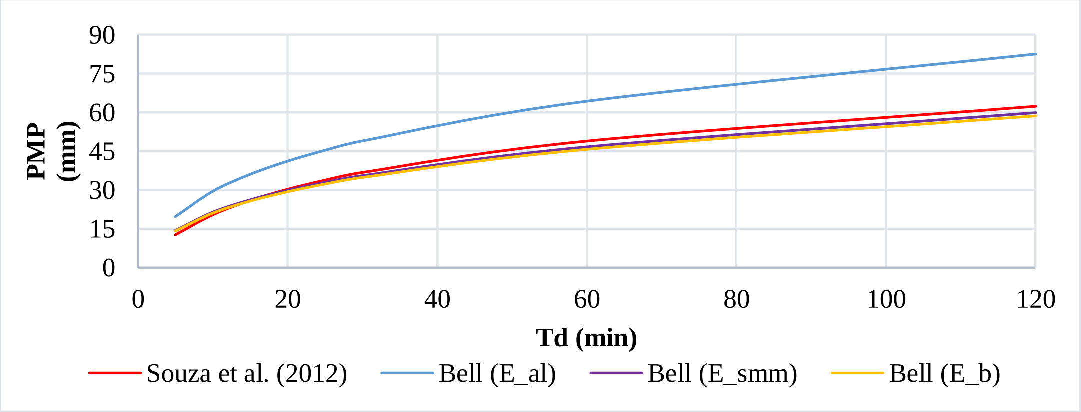

Figure 8. Maximum precipitation estimated for Breves, considering a return period of 10 years

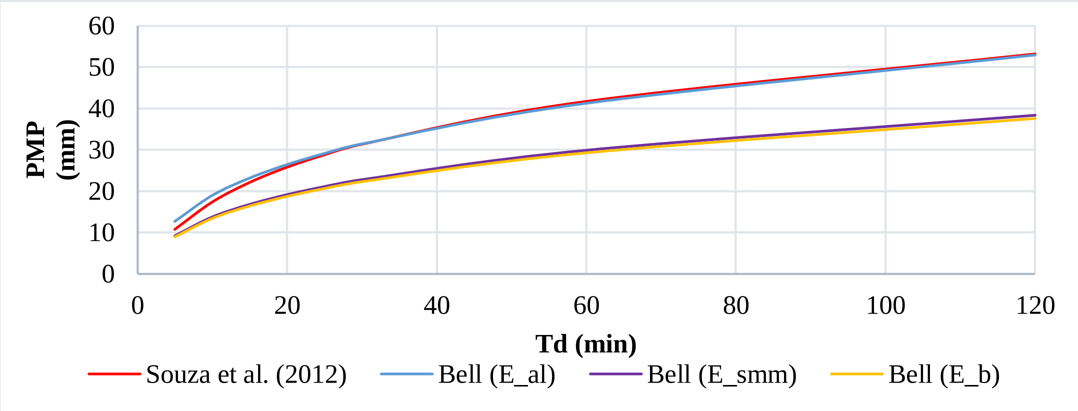

Figure 9. Maximum precipitation estimated for Breves, considering a return period of 5 years

The results presented a great approximation of the maximum precipitation estimated by the Bell's method and calculated by the Souza et al [3] rainfall equation for rains with a return period of up to 5 years, although, in this condition, the estimated values for the rainfall station *Breves* and *São Miguel dos Macacos* have been further from the reference (rain equation). These results point to the rain equation used as a more appropriated alternative methodology for determining project rainfall with short return periods, such as those used for the design of urban minor drainage projects.

For the other return periods tested, a tendency was repeated that the maximum precipitation estimated by the Bell's method for *Breves* and *São Miguel dos Macacos* stations would have results closer to those calculated by the rain equation while those estimated for *Antônio Lemos* Station would be farther from the reference values. This difference between the data presented by each station may have been due to its different locations and analysis periods, which result in greater variability of the initial precipitation data collected. Moreover, considering that the base periods of the data for *Breves* and *São Miguel dos Macacos* consider older years compared to the third one, from which the most current data were obtained, the trend presented may indicate the necessity to update the rainfall equation studied to better adjust to nowadays' reality.

It was also noticeable that this distance to the equation's results increased as the return period for the three stations increased, which may have been due to the distinctions between the conceptions of the two methodologies tested, as well as the database periods used.

Despite the previous considerations, the Bell method [2] presented excellent performances when it comes to Rainfall Intensity (mm/h) estimations for the three stations and to maximum rainfall (mm) for the *Breves* and *São Miguel dos Macacos* stations and one very good performance when it comes to maximum rainfall for the *Antonio Lemos* station data. The evaluation of the concordance index between the methodologies is briefly presented in Table 3.

Table 3. Evaluation of the concordance index between the results obtained through Bell method and the rain equation

	P (mm)		I (mm/h)	
	d (%)	Classification	d (%)	Classification
E_B - Rainfall equation	97,26	Excellent	95,39	Excellent
E_SMM - Rainfall equation	97,00	Excellent	94,79	Excellent
E_AL - Rainfall equation	78,18	Very good	88,92	Excellent

5 Conclusions

Bell's methodology [2] and the intense rain equation [3] were good options for estimating maximum precipitations with short return periods, such as those used in urban minor drainage infrastructure's projects.

In addition, the better fitting of the values obtained from the rain equation [3] and the Bell methodology [2] for the two stations that consider an older database compared to the one that provided the most up-to-date rainfall data may be indicative of the necessity to update the rain equation in discussion, since this methodology is likely to become obsolete due to the periodic need to incorporate more recent data into the database used in its determination.

Finally, considering that the best results have been obtained from the methodology that uses a larger data series, the use of Bell's methodology to estimate the probable maximum precipitation and rainfall intensities is applicable and consistent.

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