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MAXIMUM FLOW STUDY BY THE HYDROGRAM METHOD FOR A WATERSHED IN THE SOUTH OF SANTA CATARINA, BRAZIL

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ABSTRACT

Knowing the maximum flow and its return period is extremely important for safely dimension hydraulic projects for flood prediction and control and also water erosion prediction. Thus, this study aimed to evaluate Capivari river watershed maximum flow, located in south of Santa Catarina, that has a flooding history. The method used was The United States Soil Conservation Service (SCS) Triangular Unit Hydrogram method (current Natural Resources Conservation Service), and, for effective rainfall, the US Curve Number (SCS-CN) method is used. To estimate the maximum flow in the watershed, three background moisture scenarios (CNI, CNII and CNIII) and six empirical equations proposed for rural watersheds were adopted to calculate the concentration time. To evaluate the observed upstream flow, a 34-years historical series was used, measured at the São Martinho downstream fluviometric station (code 84598002), located in the outlet section of the study watershed. The results showed that the maximum flows estimated by the SCS-CN method for the conditions of CNII and CNIII had greater differences (-198% and -287%) compared to the observed flow. The smallest differences were verified for the CNI condition for all the analyzed return periods (2, 5, 10, 15, 20, 25, 50 and 100). Also, it was observed that, the longer is the return period, smaller the difference among the maximum observed and estimated flows, and, the smallest was verified for the 50-year period, indicating that this is the most appropriate for studies of extreme events in the study watershed.

Keywords: SCS Curve Number; Time of Concentration; Effective Rainfall.

RESUMO

Estudo da vazão máxima pelo método do hidrograma para uma bacia do sul de Santa Catarina, Brasil. Conhecer a vazão máxima e seu período de retorno é de extrema importância para projetos que necessitam dimensionar com segurança obras hidráulicas, para predição e controle de inundações e na predição de erosão hídrica. Assim, o presente trabalho objetivou avaliar a vazão máxima da bacia hidrográfica do rio Capivari, localizada no sul de Santa Catarina, com histórico de inundações. Foi utilizado o método do Hidrograma Unitário Triangular do Soil Conservation Service (SCS) dos Estados Unidos (atual Natural Resources Conservation Service). Para a chuva efetiva utilizou-se o método Curve Number (SCS-CN) dos EUA. Para estimar a vazão máxima da bacia foram adotados três cenários de umidade antecedente (CNI, CNII e CNIII) e seis equações empíricas propostas para bacias rurais, para calcular o tempo de

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concentração. Na avaliação da vazão máxima observada, utilizou-se uma série histórica de 34 anos, medida na estação fluviométrica de São Martinho a jusante (código 84598002), localizada na seção de saída da bacia de estudo. Os resultados mostram que as vazões máximas estimadas pelo método SCS-CN para as condições de CNII e CNIII tiveram maiores diferenças (-198% e -287%) em relação à vazão observada. Já as menores diferenças foram verificadas para a condição de CNI para todos os períodos de retorno analisados (2, 5, 10, 15, 20, 25, 50 e 100). Também, observou-se que, quanto maior o período de retorno, menor é a diferença entre as vazões máximas observadas e estimadas, sendo a menor delas verificada para o período de 50 anos, indicando que este é o mais apropriado para estudos de eventos extremos na bacia de estudo.

Palavras-chave: Curve Number SCS; Tempo de Concentração; Chuva Efetiva.

INTRODUCTION

Knowing the maximum flow and its return period is extremely important for projects that need to safely and efficiently design hydraulic structures. In addition, this knowledge extends to controlling floods, predicting water erosion, among others. The temporal sequence of these flows, related to the risk of occurrence, can be analyzed by a flood hydrograph (or project hydrograph). This hydrograph is characterized by volume, temporal distribution and maximum flow rate. When a time series of measured flow data exists at the site, the maximum flow can be estimated by analyzing extreme event frequencies from measured data. However, when there is no measured data or these are insufficient to assess the occurrence of these flows, hydrological models that transform project rainfall into project flow can be used (Beskow, 2015; Cunha et al., 2015). According to Abreu et al. (2017), most small and medium watershed in the world and in Brazil do not have rainfall and flow measurements, making it difficult to characterize the design rainfall and, consequently, the design hyetographs, which is the main input into rainfall-runoff models to generate the project hydrograph. In this case, the flood hydrograph can be obtained from a synthetic unit hydrograph (Chow et al., 1998). This method was proposed by Sherman (1932), who considered in his formulation that the hydrographic watershed responds linearly to an effective precipitation unit, uniform in time and space. Therefore, the unit hydrograph is a transfer function between effective precipitation and runoff (USDA, 2007). The unit hydrograph is usually obtained using a method that calculates effective rainfall, together with a transfer function, which allows the temporal distribution of the total rainfall volume (Cunha et al., 2015). This method is simple and practical for hydrographs calculations from rainfall and has a good acceptance (Silveira, 2016). The main input variables required by this method are rainfall discretization interval, concentration time and watershed area (Cunha et al., 2015).

There are several models of synthetic unit hydrographs, among which the hydrographs developed by Snyder (Snyder, 1938), Clark (Clark, 1945), SCS (Mokus, 1945), Geomorphological (Rodriguez-Iturbe and Valdes, 1979) and Nash (Nash, 1957). These models differ, mainly, in the equations used to estimate the peak time and the shape of the hydrograph (Tucci, 1998).

Inocentte and Chaffe (2017), based on a review study, verified that the triangular unit hydrograph of the SCS (Soil Conservation Service, current Natural Resources Conservation Service) is one of the most commonly used in Brazil. This hydrograph was based on the analysis of a large number of hydrographs obtained in instrumented watershed with a wide range of areas and geographic locations in the USA (SCS, 1972) to calculate maximum flows from design rainfall (Silveira, 2016).

In project rainfall estimation, one of the commonly used methods is the Curve Number (CN) or SCS-CN, originally developed in the 1950s by the US National Resources Conservation Service (NRCS) (USDA, 1985; Mishra and Singh, 2003). This method is widely used around the world due its simplicity, easy to understand and can be applied to small river watershed s without measured flow data (Mishra and Singh, 2003). The method requires only two parameters to estimate the surface runoff volume, which are the initial abstraction coefficient (20%) and the maximum soil water retention potential, calculated based on tabulated CN values (USDA, 1985).

The SCS-CN method uses tabulated CN values to represent soil and land cover characteristics. However, due to the lack of detailed information, mainly on soil characteristics, the CN value presents many uncertainties. In addition, the method uses the watershed's concentration time to calculate the maximum flow, which also presents many uncertainties, since it can be obtained from empirical and semi-empirical equations (Fernadez et al., 2017). The formulation of such equations is based on watershed data with local and specific characteristics that are often not representative for other watershed. Therefore, the concentration time calculated by these equations does not always reflect the reality of the watershed.

Studies have evaluated and discussed the limitations and inconsistencies of this method, such as: Fang et al. (2008); Hawkins et al. (2009); Yuan et al. (2014), Cunha et al., (2015); Ajmal et al. (2016); Fernandes et al. (2017); Valle et al. (2019); Walega et al. (2019).

In this context, the present study aimed to evaluate the maximum flow for a watershed located in the south of Santa Catarina, using the SCS triangular unit hydrograph, considering three background scenarios of soil moisture for the CN.

MATERIALS AND METHODS

The study area is a watershed of the Capivari river watershed, comprising the cities of São Martinho and São Bonifácio, located in the south of Santa Catarina State, Brazil (Figure 1). This watershed has an area of 620.85 km² and is predominantly rural, with a small urban area. The Capivari river, which is the main river in this watershed, is a tributary of the Tubarão River. Delimitation of the study watershed considered the São Martinho downstream river station (code 84598002) as the control section (outlet). This station is one of the watershed's data collection and monitoring carried out by the National Water and Basic Sanitation Agency (ANA, 2019).

The region climate, according to Köppen classification, is the Cf type, that means, Mesothermal Without dry season, which includes two subtypes, Cfa (Mesothermal Subtropical) with hot summer, and Cfb (Wet Mesothermal Temperate) with mild summer (Pandolfo et al., 2002; Alvares et al., 2013). The average annual rainfall in the watershed region is 1400 mm, with the higher concentration of rainfall in the summer months (December, January, and February) (Pandolfo et al., 2002). According to SDS (2017), the relief of the watershed region is strongly undulating, with slopes ranging between 20% and 45%.

Soil and Land Use and Occupation Data

Maps of land use and occupation and soil hydrologic group were used to define the mean CN of the Capivari river watersheds (BHRC). Four RapidEye images were used to elaborate the land use and occupation map of the study watershed, corresponding to the dates of 9, 10, 17, and 29 of December 2012, due to the absence of clouds. These images were obtained on the webpage of the Geocatalogo of the Brazilian Ministry of the Environment (http://geocatalogo.mma.gov.br/index.jsp). Six classes of land use and occupation, representative of the study area, were defined: i) native forest; ii) water; iii) pasture; iv) reforestation; v) exposed soil; and vi) urban area. The images were processed in ArcGIS 10.0 software, using the automatic classification method based on max-likelihood.

The main soils of the Capivari river watershed were classified into three hydrological groups (B, C, D), based on the soil survey carried out in 2004, at a scale of 1:250,000 (EMBRAPA, 2004), using the criteria proposed by Sartoti et al. (2005), which were considered closer to Brazilian soils.

For different moisture conditions in the CN II condition, the method indicates corrections for the CN values, based on the following previous moisture conditions: CN I for dry soil and CN III for wet soil close to saturation (Jeon et al., 2014). The most impermeable classes have higher CN and, therefore, indicate less infiltration potential and greater surface water runoff. In the present study, the maximum flow was estimated with CN values for the three previous soil moisture conditions, in order to verify wich one is closest to the maximum flow observed.

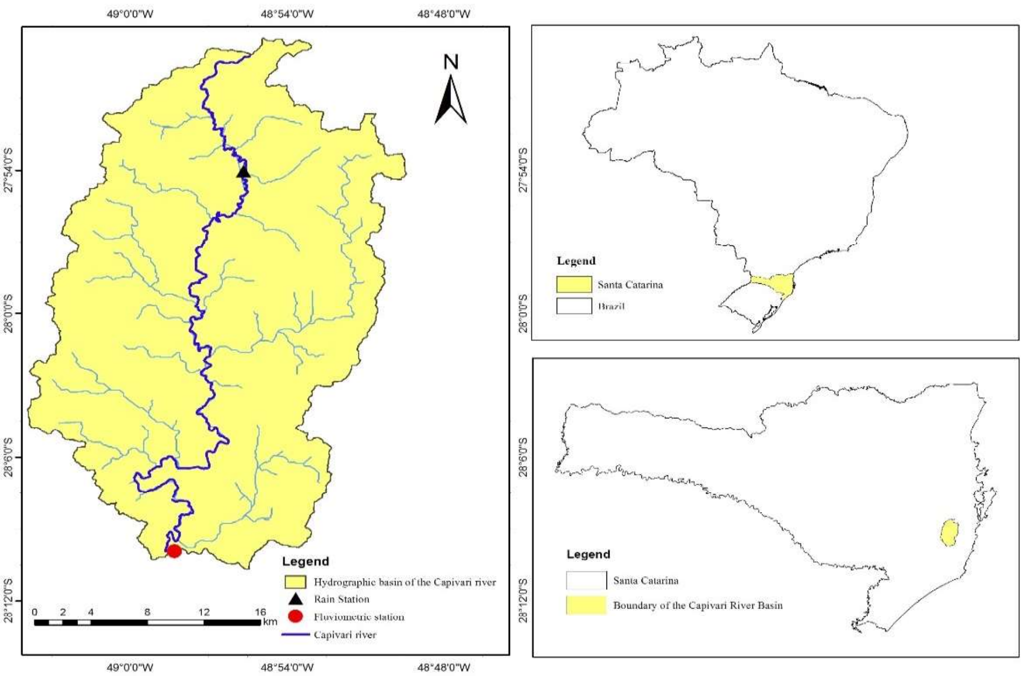

Figure 1. Location of the Capivari river watershed and used stations.

Hydrological Data

To calculate the effective rainfall, daily data of the period from 1976 to 2017 of the rainfall station code 02748018 were used. To calculate the maximum flow, daily data of the period from 1981 to 2014 of the São Martinho downstream river station (code 84598002) were used. These two stations are also ANA responsibility.

Maximum Instantaneous Flow Observed for Different Return Periods

Maximum flows were calculated for return periods of 2 to 100 years, using the Gumbel-Chow distribution (Back, 2001), by the analysis of 100 rainfall stations distributed through Santa Catarina state found that the Gumbel-Chow distribution was the best fit for the most of them. As the historical series of maximum flow correspond to the average of two daily-readings made with limnimetric rulers, at 7 a.m. and at 5 p.m., the maximum instantaneous flow was obtained with the application of the Füller coefficient (1914) (Villela and Mattos, 1975), which can be determined by:

$$\lambda = 1 + \frac{2.6}{A^{0.3}} \qquad (1)$$

where λ is the Füller coefficient (dimensionless); and *A* is the drainage area (km²) of the study area. Thus, the maximum instantaneous flow was calculated by:

$$Qmx = \lambda\, Qmd \qquad (2)$$

where *Qmx* is the maximum daily flow ($m^3.s^{-1}$); and *Qmd* is the average daily flow ($m^3.s^{-1}$).

To verify the adjustment of the Gumbel-Chow distribution, the Kolmogorov-Smirnov (Kite, 1977) and Anderson Darling (Neghettini and Pinto, 2007) tests were applied. In the adherence test, a significance level of 5% (α = 0.05) was adopted. The observed frequency and plot position on the graph were calculated using Cunnane's formula (Back, 2013), which is given as a compromise formula, with good results for most statistical distributions used in hydrology. The Kolmogorov-Smirnov test compares the maximum difference (Dmax) between theoretical and observed frequencies, according to Equation 3:

$$D_{max} = Maximo[|Fobs - Fcalc|] \qquad (3)$$

where D_{max} is the test statistic, Fobs is the observed flow frequency, *Fcalc* is the calculated flow frequency according to the tested distribution. The D_{max} being compared to the critical value ($D_{critical}$) compared to the significance level of 5%. The Anderson and Darling test statistic are calculated by Equation 4:

$$A^2 = -N - \sum_{i=1}^{N} \frac{(2i-1)\{lnF_X(x_{(i)} + ln[1 - F_X(x_{(N-i+1)})]\}}{N} \qquad (4)$$

where $X_{(1),}$ $X_{(2),}$ ... $X_{(n)}$ represent the observations ordered in ascending order; *FX(x)* is the density function, according to the null hypothesis; *N* is the number of events in the analyzed series . If the A^2 statistic results in a critical value, the empirical *FN(X)* and theoretical *FX(X)* distributions differ greatly from each other and, consequently, the null hypothesis (adherence of the data to the studied distribution) must be rejected.

Design Rainfall

Design hyetographs were obtained using Equation 3 (Intensity, Duration, and Frequency), prepared by Aguiar et al. (2019) for the used rainfall station (code 02748018):

$$i = \frac{882.54.\ T^{0.172}}{(t + 9.85)^{0.726}} \qquad (5)$$

where *i* is the rainfall intensity ($mm.h^{-1}$); *T* is the return period, in years (2 ≤ T ≤ 100); *t* is the rainfall duration, in minutes (5 ≤ *t* ≤ 1440).

Considering the spatial variation of rainfall, the Reduction Factor (RF) was applied, which aims to reduce the point rainfall to the average rainfall in the watershed. The present study used the method recommended by DNIT (2005), in which the reduction factor is calculated by:

$$RF = 1 - 0.1\log\left(\frac{A}{25}\right) \qquad (6)$$

Since A = 620.85 km², the RF value is 0.86.

When defining rainfall, in addition to intensity, duration and frequency, it is necessary to take into account its distribution over its duration (Tucci, 2014). The temporal distribution curves presented by Huff (1967) have been one of the most used methods to define temporal distribution pattern of heavy rains, when local information is not available (Abreu et al., 2017; Back, 2018). This method allows for a less arbitrary temporal rainfall disaggregation, being possible the adaptation to local characteristics, and can be applied according to the area and duration of rainfall characteristic of the location (Abreu et al., 2017). Thus, in the present work, the temporal distribution of rainfall intensity (i) was performed considering the curve with 50% frequency of the 1st quartile of Huff (1967), chosen due to the fact that in Santa Catarina rain type I predominates, according to studies by Back (2011) for the Urussanga region; Back (2009) for Caçador; Back et al. (2011) to Florianópolis; Back et al. (2015) to Chapecó; Back (2018) to the northern plateau; and Back (2021) for the mountain region of Lages and São Joaquim.

Curve Number Method (SCS-CN)

The SCS method was used to estimate the effective rainfall, (NCRS, 1985).

$$Q = \begin{cases} \& \qquad 0, & for \quad P \le Ia \\ \& \dfrac{(P-Ia)^2}{P - Ia + (-254 + 25400/CN)}, & for \quad P > Ia \end{cases} \qquad (7)$$

where Q is the effective precipitation accumulated over time (mm); P is the accumulated precipitation over time (mm); Ia is the initial abstraction (mm); and CN is the curve number determined by land use.

The CN values are related to the physical conditions of the watershed (land cover, soil type and antecedent moisture). In the present work, the CN values were obtained by combining, with the QGIS 2.18 software, overlaying the map of soil hydrological groups with land use and occupation map. This combination resulted in several CN values, adopting the average value obtained by the average weighted by the area of each hydrological group.

Estimation of Maximum Flow Using the SCS-CN Synthetic Unit Hydrograph

The maximum flow was estimated using the SCS-CN unit hydrograph, determined based on physical characteristics of the Capivari river watershed and time-related parameters. The SCS-CN method calculates the time parameters of the unit hydrograph by Equations (8) to (11) (Chow et al., 1988). In the present study, the time of concentration was calculated using the Corps Engineers equation (Equation 11). According to Silveira (2005), this equation is recommended for large rural watersheds, which is the case of the Capivari river watershed. The calculations used a concentration time of 11.7 hours and a 90 minutes of rain duration.

$$t_c = 0.191L^{0.77}S^{-0.19} \quad (8)$$

$$T_p = t_b + \frac{t}{2} \quad (9)$$

$$t_b = Tp + 1.67 \times T_p \quad (10)$$

where *tc* is the time of concentration (min); *L* is the length of the main river (km); *S* is the mean slope of the watershed (m.m^{-1}); T_p is the peak time of the hydrograph (hours); t_b is the base time (hours); *t* is the rainfall duration (hours).

The maximum flow of the triangular unit hydrograph was calculated by:

$$Q_p = \frac{0.208 \times A}{T_p} \quad (11)$$

where Q_p is the maximum flow (m^3.s^{-1}.km^{-2-1}).

For this reason, it was necessary to compare the estimated flows hydrographs (Qest) with the observed flows (Qobs) at the station fluviometric analysis, and for that the percentage error (ER%) was used, according to:

$$ER = \left(\frac{Q_{Obs} - Q_{Est}}{Q_{Obs}}\right) \times 100 \quad (12)$$

where *ER%* is the percentage or relative error (%), is the observed flow (m^3.s^{-1}) e is the flow estimated by the model (m^3.s^{-1}).

Six equations recommended for rural watersheds were used to evaluate the t_c influence on the estimation of maximum flows by the SCS-CN method: Kirpich, Ven te Chow, Dooge, Johnstone, Corps Engineers, and George Ribeiro. These equations were extracted from the review work done by Silveira (2005). In this evaluation a return period of 100 years and a CN value of 88.5 were used, calculated for the three background moisture scenarios (CNI, CNII and CNIII).

RESULTS AND DISCUSSION

Maximum Daily Flow Observed for Different Return Periods (T)

Figure 2 shows the Gumbel distribution fitting to the series of annual maximum flows at the São Martinho downstream station. The distribution fitted well, being considered adequate by the Kolmogorov-Smirnov and Anderson-Darling adherence tests at the 5% significance level.

The maximum flow estimated using the probability distribution was used as a reference to evaluate the estimates made with the SCS-CN hydrograph method. However, it should be noted that this estimation is also subject to errors. There are several probability distributions that can be used to estimate maximum flow, among which the following stand out: log-normal distribution, Gumbel distribution, generalized extreme value (GEV) distribution, type III Pearson distribution, type III log-Pearson distribution, and Weibull distribution (Kite, 1977; Naghettini and Pinto, 2007). In the case of the São Martinho downstream station, adhesion tests did not reject the Gumbel distribution. Back (2018) observed that, for return periods up to 100 years, the maximum flows obtained by various probability distributions differed less than 10%, showing that all of them can be used to estimate flows.

In addition, DNIT (2005) points out that the maximum flows obtained by different distributions begin to diverge appreciably only for a return period higher than 100 years.

Tucci (2009) also comments out that the maximum flow values obtained by different distributions begin to diverge appreciably when the years of observed flow data are less than the analyzed return period. For example, if it is necessary to estimate the maximum flow of 50 years of the return period, but there are only 20 years of observed data.

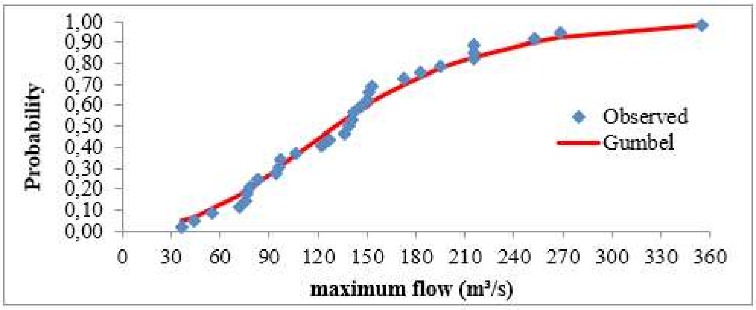

Figure 2. Gumbel distribution fitting to the series of annual maximum flows at the São Martinho downstream station, Santa Catarina State.

Table 1 shows the maximum daily flows calculated by the Gumbel distribution method and corrected by the Füller coefficient, for different return periods.

Table 1. Maximum flow observed for different return periods (T).

T (years)	Maximum Flow (Gumbel) ($m^3.s^{-1}$)	Maximum Flow (Corrected by Füller) ($m^3.s^{-1}$)
2	127.10	175.17
5	200.26	275.89
10	248.67	342.58
15	275.98	380.20
20	295.10	406.55
25	309.86	426.84
50	355.20	489.35
100	400.24	551.40

In the correction of maximum daily flows into maximum instantaneous flows (Equation 1), a Füller correction factor of 1.378 was obtained. It should be noted that the Füller correction factor was based on observations made in large watersheds in the eastern USA. Another aspect is that, in addition to the watershed area used in the calculation of this factor, other morphometric characteristics such as watershed slope, watercourse sinuosity, and watercourse slope influence storage and flow, affecting the Füller correction factor. However, the use of this factor is more justified by the absence of more adequate methods to make the corrections than by the precision that the formula provides.

Effetive Rainfall by SCS-CN Method

Table 2 shows the CNII values determined for the Capivari-SC river watershed.

Table 2. CNII values for the Capivari-SC river watershed.

Soil Hydrologic Group	Land Use	CNII	Area (%)
Group B	Forest	56	2.48
	Water	100	0.14
	Pasture	69	1.63
	Reforestation	60	0.64
	Agriculture	79	0.40
	Urban area	74	0.09
Group C	Forest	70	27.04
	Water	100	0.39
	Pasture	79	15.04
	Reforestation	73	7.06
	Agriculture	84	3.12
	Urban area	82	0.19
Group D	Forest	77	26.1
	Water	100	0.10
	Pasture	79	6.30
	Reforestation	79	7.40
	Agriculture	88	1.90
	Urban area	86	0.10

Figure 3 shows the land use and occupation (3A) and the soil hydrologic groups (3B) of the study watershed. Figure 4 shows the CNII map resulting from these two maps, adopting the CN table by Sartori (2005) as a reference.

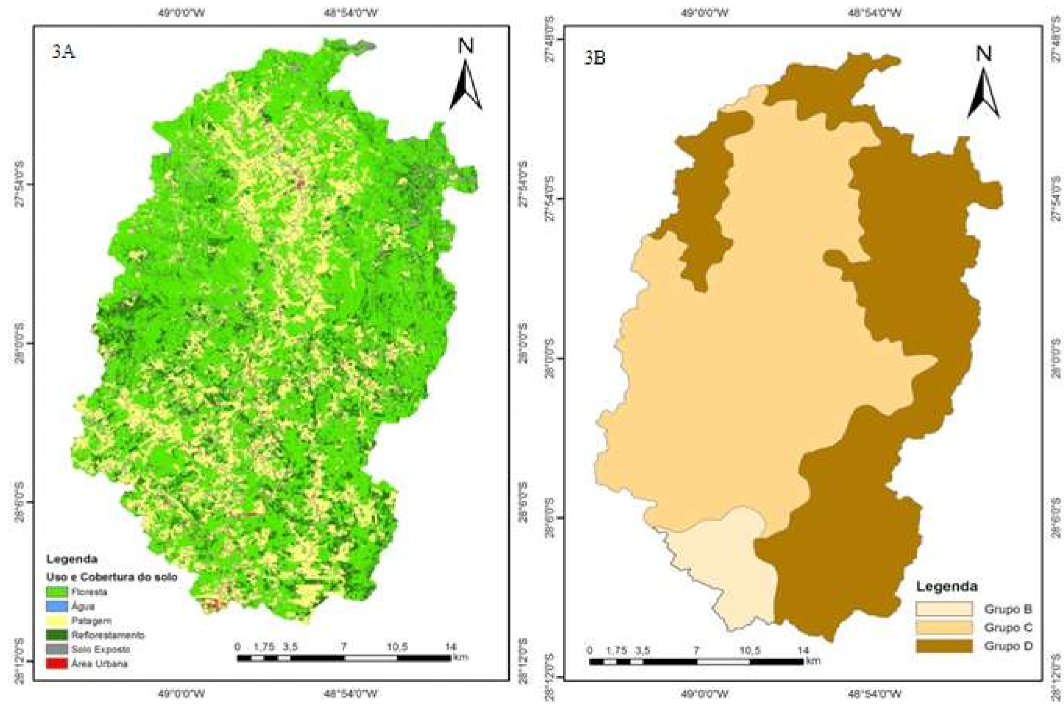

Figure 3. Map of land use and occupation (3A) and hydrologic groups (3B) of the Capivari River watersheds, Santa Catarina State.

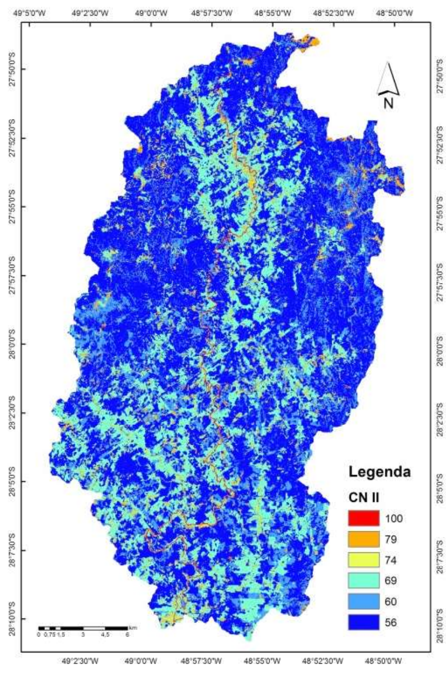

Figure 4. CNII map of the Capivari River watersheds, Santa Catarina State.

Maximum Observed and Estimated Flow for Different Return Periods

Table 3 presents morphometric parameters, the concentration time, the peak time, and the CN values for the three antecedent moisture conditions. These parameters were used to determine the SCS-CN unit hydrographs.

Table 3. Parameters determined for the Capivari River watersheds.

Parameter	Value	Unit
Drainage area (A)	620.85	km^2
Length of the main river (L)	75.00	Km
Slope (S)	0.012	$m.m^{-1}$
Concentration time (tc)	11.7	h
Peak Time (Tp)	7.02	h
Average CNI	57.5	-
Average CNII	75.5	-
Average CNIII	88.5	-

Table 4 presents the results of the 24 hydrographs obtained by the SCS-CN method for the different return periods, considering the three scenarios of antecedent soil moisture conditions

Table 4. Maximum flow calculated (*Qp*) by the SCS-CN hydrograph, and maximum flow observed (QP_{obs}) and the relative error (%) at the river station (84598002).

T (years)	*Qp* Obs ($m^3.s^{-1}$)	*Qp* (CNI) ($m^3.s^{-1}$)	ER%	*Qp* (CNII) ($m^3.s^{-1}$)	ER%	*Qp* (CNIII) ($m^3.s^{-1}$)	ER%
2	175	106	39	368	-110	677	-287
5	276	174	37	494	-79	843	-205
10	343	240	30	608	-77	988	-188
15	380	288	24	687	-81	1085	-186
20	407	327	20	747	-84	1159	-185
25	427	359	16	798	-87	1220	-186
50	489	470	4	964	-97	1418	-190
100	551	605	-10	1156	-110	1641	-198

It is observed that the estimated flows had lower ER (%) for CNI condition. This indicates that the estimated flow rates are closer to the flow rates measured in the fluviometric station code 8459800. Also, it is observed that the longer the return period, the smaller the difference between the estimated and observed maximum flows, and for the 50-year period was the closest.

Alves (2016) comments that for CNI antecedent moisture conditions, initial abstraction values are higher because the soil is dry and water infiltration is higher, which is not the case for the conditions CNII and CNIII. Durán-Barroso et al. (2016) highlight that the SCS-CN method is very sensitive to the CN value, i.e., small variations of this parameter interfere considerably with maximum flows. This is because the CN value is directly related to factors that affect surface runoff, such as soil type, land use and occupation, and soil moisture.

The CNIII condition showed the largest differences, between -198% and -287%. In turn, the CNI showed the smallest differences, ranging between -10% and 39%. This variation increases as the soil changes from dry to wet and saturated (CNII and CNIII). Furthermore, the SCS-CN method overestimates flows for the conditions CNII and CNIII. However, the flows were underestimated in the dry soil condition (CNI).

In the conditions CNII and CNIII, soil permeability tends to decrease as the CN value increases, thus increasing maximum flow. In these cases, all rainfall is transformed into surface runoff. This does not happen for the CNI scenario, where part of the rainfall is intercepted by the plants and another part infiltrates the soil, generating little surface runoff.

In determining design rainfall, one of the three antecedent moisture conditions (CNI, CNII, or CNIII) must be chosen. The designer's natural tendency is to opt for condition III, which represents the most critical situation. Notwithstanding, this tends to lead to extreme flows. Collischonn and Dornelles (2013) highlight that correcting antecedent moisture is not currently recommended, being more indicated to use CN values determined for condition II.

Several studies criticized the SCS-CN method, showing its limitations for estimating the maximum flows of watersheds. Valle Junior et al. (2019) studied a rural watershed (315.7 km^2) in the central-west of Brazil and observed that 96.7% of the evaluated values of initial abstraction (I_a) were lower than the 20% adopted by the SCS-CN method. The authors also noted that the values ranged from 0.005 to 0.455, with a median of 0.045, and recommended the use of an initial abstraction of 0.05 for watersheds with characteristics similar to the watersheds of this study.

The adopted design rainfall is another factor that can cause uncertainty when using the SCS-CN method. The measured rainfall is an indispensable information. However, it is normally considered that, for areas larger than 10 km^2, an average rainfall tends to be less than the point rainfall, being recommended the use of a reduction factor (DNIT, 2005), also called areal reduction coefficient. In Brazil, there are few studies on the areal reduction coefficient (Silveira, 2001; Santos and Naghettini, 2003). In general, it is recommended to use this coefficient based on the methodology developed with data from the United States (USWB, 1957). Studies on rainfall spatial variation and methods of determining the areal reduction factor show that errors can result in large inaccuracy in defining design rainfall and, consequently, peak flow (Osborn et al., 1980; Sivapalan and Bloschl, 1998; Wright et al., 2014).

Still regarding design rainfall, the temporal distribution also affects runoff and maximum flow values (Choi et al., 2014; Abreu et al., 2018). Canholi (2005) points out that the temporal distribution of rainfall comprises a major problem for the hydrologist, because, for each temporal distribution, there are different hydrographs. According to São Paulo (2012), the type of temporal distribution of the design rainfall and the fixing of the duration are subject to several methodological guidelines, which implies quite different results of maximum flows and flood volumes.

Additionally, Abreu et al. (2017) and Benzak et al. (2018) demonstrated that the representative Huff curves are those with 10% and 50% probability of exceedance for the 1st quartile, where the maximum rainfall intensity occurs at the beginning of the rainfall event. The authors highlight that type IV rainfall (intense precipitations of long duration greater than 12 hours) tends to produce more surface runoff, since the soil is already saturated. Benfica et al. (2000) and Monteiro and Kobiyama (2014) show that the method of temporal distribution of rainfall adopted in the preparation of the hyetograph influences the volume and maximum flow of the hydrograph.

In addition to the effective rainfall, the determination of the design rainfall requires considering aspects related to the spatial and temporal distribution of the rain . In Brazil, there is a great lack of studies to assess and determine spatial variation, with the use of generic relationships established based on the observations of the United States Weather Bureau - USWB (1957) (DNIT, 2005; Tucci, 2014). For temporal variation, in general, methods such as Alternating Blocks, the Chicago Method, or the Triangular Hyetograph are used (Chow et al., 1988; Tucci, 2014). The temporal distribution patterns established by Huff (1967) or by the SCS (1985) are also used. Thus, the definition of the design rainfall is important in flow estimation, directly influencing the rainfall-flow transformation model and impacting the format, volume, and peak of the hydrograph.

Maximum Flows Estimated with Different Concentration Times

Table 5 presents the time of concentration calculated by different methods. For the Capivari river watershed, the average value was 12.13 hours, with the highest value being 17.6 hours, calculated by the George Ribeiro equation. However, excluding the highest value (due to the maximum flow rate estimated by the hydrograph exceeded the maximum flow rate measured in the river when the concentration time used is greater than 12.08 hours), the average concentration time is 11.40 hours. Using various empirical equations, Kobiyama et al. (2006), Mota (2012), and Mamédio et al. (2018) also found different values of *tc* for watersheds in southern Brazil.

Table 5. Time of concentration (t_c) obtained by the different methods.

Method	**t_c (hours)**
Ven Te Chow	10.11
Johnstone	10.40
Kirpich	10.90
Doog	12.08
U.S. Corps of Engineers	11.70
George Ribeiro	17.60

Figure 5 shows the hydrographs obtained with different *tc* values presented in Table 5, for a 100-year return period. It can be observed that t_c has a strong influence on the maximum flow estimate. Peak flows were similar among Kirpich, Ven te Chow, Johnstine, and Corps Engineers methods, which are all the methods to use the same variables (slope and length). It was observed also by Silveira (2005). On the other hand, the George Ribeiro method, which uses the *A* value, tends to overestimate *tc* and, consequently, generates lower peak flows.

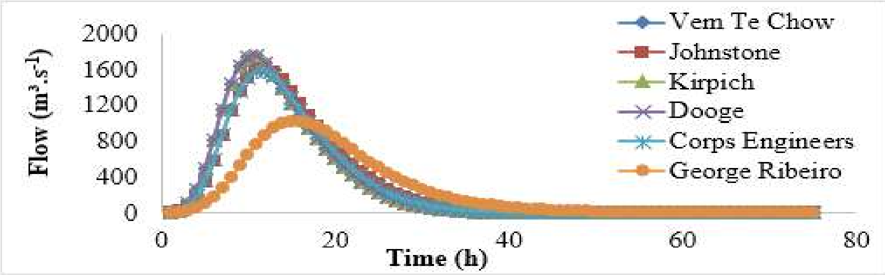

Figure 5. Hydrographs calculated with different concentration times.

Moreover, Fernandes et al. (2017) found that it is possible to identify the impact of t_c on the hydrograph shape. In their study, longer times (19 and 24 hours) lead to hydrographs with a flatter shape and smaller flows. In turn, a smaller t_c leads to sharper hydrographs and higher flows. This pattern can be observed in Figure 4, too. Azizian (2018) also comments on the impact of uncertainties in calculating t_c on peak flow estimation by hydrological models.

CONCLUSIONS

By three background soil moisture scenarios (CNI, CNII and CNII) and six empirical formulas, proposed for rural watersheds, the present work evaluated the influence of these parameters to estimate the maximum flow, calculated with the SCS-CN Triangular Unit Hydrogram method to the Capivari river watershed, south of Santa Catarina. Based on the results obtained, it is concluded that:

- Maximum flows increase as antecedent soil moisture conditions get closer to saturation. In the conditions CNII and CNIII, soil permeability tends to decrease as the CN value increases, thus increasing maximum flow. The results for these conditions show that all rainfall is transformed into surface runoff. This behavior does not happen when using the CNI, where part of the rainfall is intercepted by the plants and another infiltrates the soil, generating little surface runoff. In determining design rainfall, the natural tendency is to opt for condition III, which represents the most critical situation. However, this may imply obtaining overestimated flows.
- In calculating effective rainfall, the definition of the areal reduction factor, the temporal distribution, and the initial abstraction values are also sources of uncertainties that can lead to errors in estimating maximum flow.
- The maximum flows estimated by the SCS-CN method for the CNII and CNIII conditions had greater differences (-198% and -287%) compared to the Capivari river watershed observed flow. The smallest differences were verified for the CNI condition for all analyzed return periods (2, 5, 10, 15, 20, 25, 50 and 100). Also, it was observed that, the longer is the return period, smaller the difference among the maximum observed and estimated flows, with the smallest difference being found for the 50-year period, indicating that this is the most appropriate for studies of extreme events in the study watershed.

It is recommended for future research that a careful analysis is carried out to verify which values of initial abstraction, CN, and concentration time are most suitable for calculating maximum flows. Additionally, instantaneous rainfall data are recommended over daily rainfall data to calculate effective rainfall.

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