Available online at http://www.journalijdr.com

IJDR

ISSN: 2230-9926

International Journal of Development Research
Vol. 10, Issue, 12, pp. 43070-43074, December, 2020
https://doi.org/10.37118/ijdr.20709.12.2020

RESEARCH ARTICLE OPEN ACCESS

SURFACE RUNOFF ESTIMATION BASED ON THE INTENSE RAINFALL EQUATION OBTAINED BY DISAGGREGATING DAILY RAINFALL

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ARTICLE INFO

Article History:
Received 28th September, 2020
Received in revised form
21st October, 2020
Accepted 14th November, 2020
Published online 31st December, 2020

Key Words:

Terraces, Hydrology, Hydrological Modeling, Water Balance.

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ABSTRACT

Several hydrological models make use of surface runoff estimates, among which the soil water balance method developed by the Research Group on Water Resources of the Federal University of Viçosa stands out. This method, which is used in software for dimensioning terraces and other soil conservation structures, requires knowledge of the intensity-duration-frequency (IDF) equation in the site of interest. This note presents an adaptation of this method for the model of intense rainfall equation obtained by disaggregating daily rainfall. We used equations for estimating maximum average intensities and instantaneous intensities, and compared the IDF equation to the alternative generalized equation model in soils with basic infiltration rate of 10 and 50 mm h-1. The results demonstrate that the equations presented in this article allow the use of the method of estimating the maximum surface runoff depth based on the surface water balance in places where the IDF equation is not available.

Citation: ***Álvaro José Back, Leandro do Prado Wildner and José Eloir Denardin,* 2020.** "Surface runoff estimation based on the intense rainfall equation obtained by disaggregating daily rainfall", *International Journal of Development Research*, 10, (12), 43070-43074.

INTRODUCTION

Runoff estimation is important in the simulation of various hydrological processes, such as for the generation of flood hydrographs, estimation of runoff volume, dimensioning of terraces.Pruski *et al*. (2001) highlight that several factors must be considered when designing drainage systems and protective constructions against floods and water erosion, with surface runoff being the main one. Lombardi Neto *et al*. (1994) state that the surface runoff rate is the most relevant parameter for designing level terraces, while the runoff volume is the most important factor for gradient terraces. Griebeler *et al*. (2001) point out that knowledge of the runoff volume is sufficient when the objective is to retain or store water, butwhen the purpose is to conduct excess water, it is more important to know the flow rate. One of the most used methods to estimate surface runoff is the Curve Number method (CN-SCS) developed by the National Resources Conservation Service (NRCS), formerly the United States Soil Conservation Service (SCS), linked to the United States Department of Agriculture (SCS-USDA). However, Pruski *et al*. (2001) observed that the CN-SCS method leads to increasing values of surface runoff with the increase in the duration of the rainfall event, which is not consistent with reality.Pruski *et al*. (1997) developed a method to determine the surface runoff volume in locations where the intense rainfall equation (intensity, duration, and frequency – IDF) is known. This method is used in software for dimensioning terraces (Pruski *et al*., 1996) and for calculating road drainage systems (Silva, 2011). When comparing surface runoff estimation methods, Pruski *et al*. (2001) concluded that the method proposed by Pruski *et al*. (1997) better described the decrease of surface runoff with the increase of the infiltration rate, also presenting surface runoff depths lower than those of the CN-SCS method for high soil water infiltration rates. Almeida *et al*. (2016) compared surface runoff estimates obtained with the CN-SCS method and with the method of Pruski *et al*. (1997), concluding that the CN-SCS method leads to overestimated surface runoff values. Intensity-duration-frequency (IDF) equations are determined based on short rainfall events, usually from 5 to 1,440 min. Thus, intense rainfall data recorded in rain gauges are needed. In several countries, including Brazil, rainfall data are relatively scarce. When available, these data usually do not correspond to very long series, besides showing flaws in the records. It is important to highlight that the analysis of rainfall data is very laborious, so there is a lack of IDF equations from updated data (Campos *et al*., 2014; Bielenki Júnior *et al*., 2016). An alternative to overcome this lack of rainfall data is determining short rainfall events by disaggregating maximum daily rainfall, and then obtaining the IDF equation (Rangel and Hartwig, 2016). Among the disaggregation methods used in Brazil, the isozones method (Basso *et al*., 2016) and the method of rainfall-duration relationships (CETESB, 1986) stand out, the latter being the most used.Back (2020) presented a model of intense rainfall equation based on disaggregation of maximum daily rainfall. The author demonstrated that, in addition to improving estimates, this model has the advantages of facilitating the update only by changing maximum daily rainfall, also facilitating spatial representation.Thus, this study adapts the model developed by Pruski (1997) to estimate surface runoff, using the alternative model of intense rainfall equation based on disaggregation of maximum daily rainfall.

METHODS

Surface water balance method: Pruski *et al*. (1997) used a of surface water balance model to estimate the maximum surface runoff volume, described by the following equation:

$$R = P - Ia - L - Ev \quad (1)$$

where:

R = maximum surface runoff depth, mm;
P = total rainfall, mm;
Ia = initial abstractions, mm;
L = soil water infiltration, mm; and
Ev = evaporation, considered null, mm.

The total rainfall, corresponding to the duration t, in min, obtained by the alternative intense rain equation, based on the breakdown of daily rain proposed by Back (2020), can be expressed by

$$P = \left(\frac{t}{27{,}9327+3{,}8346t^{0{,}7924}}\right) P_{1day} \quad (2)$$

where:

P is the rainfall height, mm;
I_m is the rainfall intensity, mm h^{-1};
t is the rainfall duration, min; and
$P_{1\ day}$ is the maximum daily rainfall, mm.

Then the maximum average rainfall intensity (mm h^{-1}), which is constant for a rainfall event with duration is given by:

$$I_m = \left(\frac{60}{27{,}9327+3{,}8346t^{0{,}7924}}\right) P_{1day} \quad (3)$$

Deriving equation 3 in relation to time, the equation is obtained to estimate the intensity of instantaneous precipitation (Ii), as follows:

$$I_i = \left(\frac{(27.9327+3.8346t^{0{,}7924}) - t(3.038537t^{-0.2076}}{27.9327+3.8346t^{0{,}7924}}\right) 60P_{1day} \quad (4)$$

Pruski *et al*. (1997) demonstrated that both I_m and I_i decrease with increasing rainfall duration (t), with the maximum runoff (R) corresponding to the moment when I_i equals the soil water infiltration rate (Ti). For the equations developed by Back (2020) the duration of the rain in which the maximum runoff occurs can be obtained by solving equation 5 using numerical methods, such as the Newton-Raphson method:

$$\left(\frac{(27.9327+3.8346t^{0{,}7924}) - t(3.038537t^{-0.2076}}{27.9327+3.8346t^{0{,}7924}}\right) 60P_{1day} - Ti = 0 \quad (5)$$

In the water balance (equation 1) the initial abstractions (Ia) are calculated using the Soil Conservation Service method (SCS, 1972). Pruski *et al*. (1997) established the CN values according to the basic water infiltration rate (TIB) value.

The time corresponding to the occurrence of the initial abstractions is obtained using the equation.

$$T_{Ia} = \frac{I_a}{I_m} 60 \quad (6)$$

where: TIa is the time interval between the beginning of the rain and the beginning of the runoff, in minutes

Accumulated infiltration is calculated using the equation

$$L = \frac{T_i T_{inf}}{60} \quad (7)$$

where Tinf is the duration of the infiltration (min), which is obtained using:

$$Tinf = t - t_{ia} \quad (8)$$

Once the values of P, Ia and L for the duration of precipitation obtained by equation 5 are determined, the value of R is obtained by equation 1From equation (5), it can be concluded that for each soil condition, given by Ti, and for each hydrological condition, given by the local rainfall equation, there is a rainfall duration (t) that produces the maximum runoff (R), which is determined by equation (5).

Application of methods

For the application of the method, two conditions of soil water infiltration rate were considered (10 and 50 mm h^{-1}, respectively) along with the data from the intense rainfall equation in Chapecó, SC (Back *et al*., 2019), where the IDF equation is given by:

$$I_m = \frac{991.22T^{0.166}}{(t+9.8)^{0.724}} \quad (9)$$

For a 10-year return period, the alternative equation (Back, 2020) is given by:

$$I_m = \left(\frac{60}{27.9327+3.8346t^{0.7924}}\right) 146.8 \quad (10)$$

Two conditions of two conditions of water infiltration rate in the soil, respectively 10 and 50 mm h^{-1}, were also considered.

Table 2. Results of the surface water balance calculated with the intensity-duration-frequency (IDF) equation and with the alternative intense rainfall equation.

Parameters of the surface water balance model	Soil characteristic			
	BIRof 50 mm h^{-1}		BIRof10 mm h^{-1}	
	IDF Equation	Back (2020) Equation	IDF Equation	Back (2020) Equation
I_a –Initial abstractions (mm)	3.24	3.24	1.57	1.57
T_{Ia}– Rainfall duration to reach initial abstractions (min)	0.74	0.70	0.35	0.32
t – Rainfall duration to reach maximum surface runoff (min)	27.0	29.1	184.6	175.7
I_m– Maximum average intensity (mm h^{-1})	106.7	105.7	32.0	34.1
P – Rainfall height (mm)	48.1	51.2	98.4	99.8
L – Infiltration depth (mm)	21.9	23.7	30.7	29.2
R–Maximum surface runoff (mm)	22.9	24.3	66.2	69.1

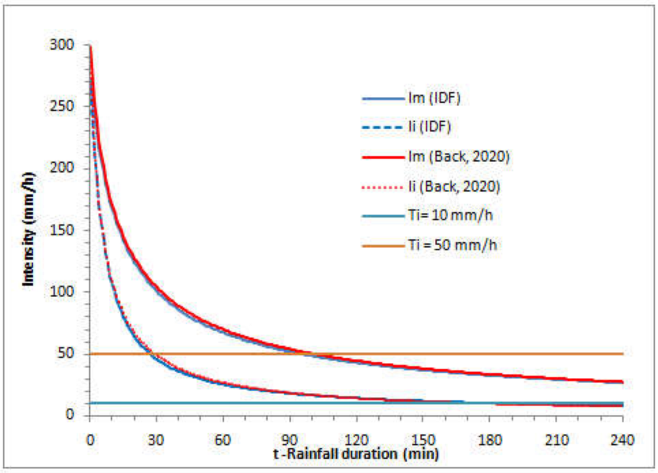

Figure 1. Maximum average intensity (I_m) and instantaneous intensity (I_i) estimated with the intensity-duration-frequency (IDF) equation and the equation proposed by Back (2020) for Chapecó, SC, Brazil

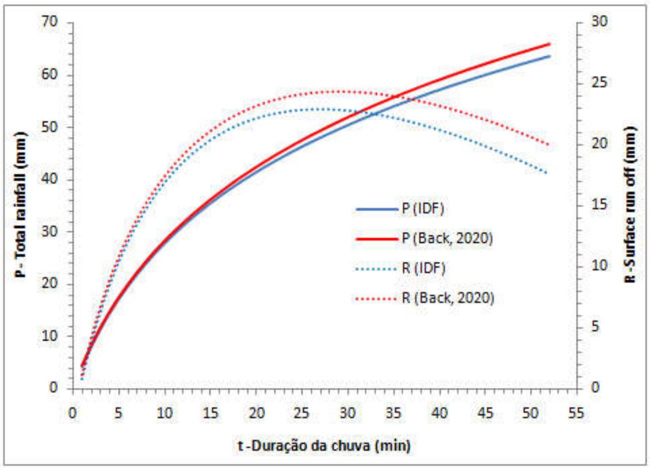

Figure 2. Total rainfall (P) and surface runoff depth (R) estimated with the intensity-duration-frequency (IDF) equation (in blue) and the equation proposed by Back (2020) (in red) for Chapecó, SC, Brazil, in soil with BIR of 50 mm h^{-1}

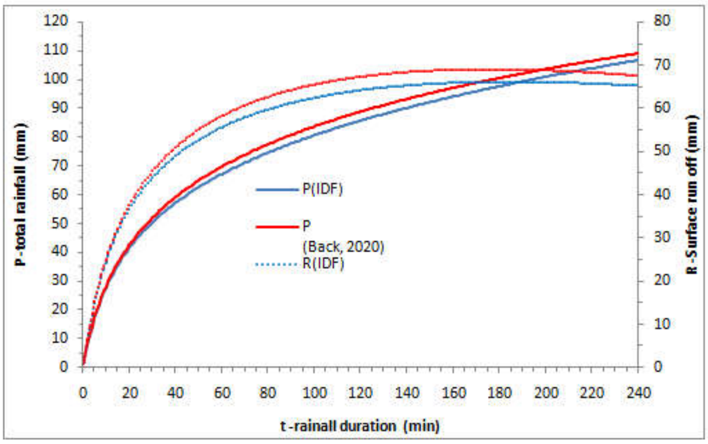

Figure 3. Total rainfall (P) and surface runoff depth (R) estimated with the intensity-duration-frequency (IDF) equation (in blue) and the equation proposed by Back (2020) (in red) for Chapecó, SC, Brazil, in soil with BIR of 10 mm h^{-1}

RESULTS AND DISCUSSION

Table 2 shows the values of the water balance parameters estimated with the two methods analyzed. The valuesof initial abstractions were 3.24 and 1.57 mm for soils with BIR of 50 and 10 mm h^{-1}, respectively. These values are relatively low due to the high CN-SCS values assumed in the method (respectively, 94 and 97) (Table 1). Thus, for the soil with BIR of 50 mm h^{-1}, initial abstractions are reached with 0.70 minutes, for both the IDF equation and the alternative equation. For the soil with BIR of 10 mm h^{-1}, this duration is 0.35 minutes when estimated with the IDF equation, and 0.32 minutes when estimated with the alternative equation. It is noteworthy that IDF equations are usually adjusted for durations from 5 minutes, which is considered the shortest feasible duration to be obtained in rain gauge readings. Some authors adjusted IDF equations to durations equal to or greater than 10 minutes (Silva *et al*., 1999; Pinto, 1999; Freitas *et al*, 2001; Silva *et al*., 2002, DAEE, 2018). Although the differences in the T_{Ia}values obtained by the methods are small and the duration range hinders the estimation, the values have little influence on surface runoff depth estimation. For the soil with BIR of 50 mm h^{-1}, the duration of the rainfall eventwith maximum surface runoff was estimated to be 27.0 minuteswith the IDF equation, and 29.1 minutes with the alternative equation. For the soil with BIR of 10 mm h^{-1}, these values are, respectively, 184.6 and 175.7 minutes. The differences in the values obtained with the different intense rainfall equations are less than 10%. Back (2020) demonstrated that the proposed alternative model has the advantage of estimating rainfall intensity with a lower standard error of estimate than the IDF method.With the rainfall duration, the values of total rainfall heights, infiltration, and surface runoff are obtained. For the soil with BIR of 50 mm h^{-1}, the estimated runoff depth was 22.9 mm and 24.3 mm, respectively, for the IDF equation and the alternative equation.

For the soil with BIR of 10 mm h^{-1}, R values were 66.2 mm and 69.1 mm. Differences between infiltrationdepths were less than 7%. Figure 1 shows the variation of the maximum average intensity and the instantaneous rainfall intensity over the duration of the rainfall event, for each type of intense rainfall equation. As highlighted by Pruski *et al*. (1997),$I_m$and I_i decrease with increasingrainfall duration. Moreover, the equation proposed by Back (2020) reproduces the characteristics of the IDF equation in such a way that the time differences for I_i to equal the BIR can be considered insignificant.Figure 2 shows the total rainfall heights and the surface runoff depth, estimated with the two models of intense rainfall equation in soil with BIR of 50 mm h^{-1}. Total rainfall has increasing values while the surface runoff depth increases until reaching a maximum point, then starting to decrease. The value to be used is the maximum value (R). The equation proposed by Back (2020) has values similar to those obtained with the IDF equation. For soils with BIR of both 50 mm h^{-1} and 10 mm h^{-1}(Figure 3), the equation proposed by Back (2020) presented slightly higher values of P and R. However, these differences depend on the adjustment of the IDF equation, and may vary for other return periods and other IDF equations.Considering that the equation proposed by Back (2020) has better estimation precision than the IDF equation obtained by disaggregating intense rainfall events, it is reasonable to accept that the parameters of the surface water balance model are also estimated with greater precision.

Conclusion

The equations presented in this article allow the use of the method ofPruski *et al*. (1997) for estimating the maximum runoff depth based on the surface water balance in places where the intensity-duration-frequency (IDF) equation is not available.This adaptation presented here allows to expand the possibilities of applying the methodology for estimating surface runoff, with the advantages of the facility of updating information on the intensity of local rain and also of the precision in estimating intense rain.

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