Determination of the Runoff Coefficient (C) in Catchments Based on Analysis of Precipitation and Flow Events

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ABSTRACT

The runoff coefficient (C) represents the relationship between the surface runoff volume and the precipitated volume. It is used in engineering projects for flood estimation methods. Although C values are tabulated and consecrated in hydrological engineering, as if they were constant, they may not correspond to the reality, because in a same catchment, they can vary according to the intensity, temporal and spatial distribution of precipitation events, humidity conditions and ground cover. This study had the objective of analyzing extreme events of precipitation and the corresponding flows to obtain experimental runoff coefficients (C) and compare them with the tabulated values. The study was conducted in four experimental catchments in the State of São Paulo, Brazil, with different land uses and soils. The runoff coefficients (C) were obtained from the analysis of hydrograms and using a digital filter, which allowed the separation of the direct runoff, of the total flow. When analyzing flow and precipitation data in different seasons of the year, selecting events of the floods of catchments and separating the flows, we observed variation of the flow coefficient values, different from those obtained from tables.

Keywords: digital filter, watershed, hydrology.

1. INTRODUCTION

The runoff coefficient (C) is defined as the ratio of the volume of water superficially drained during a rainfall over the total volume of precipitated water during a certain period of time (Bedient et al. 2013; Júnior, 2015). An important tool in hydrological studies of many engineering projects in urban and rural areas (Şen & Altunkaynak, 2006), the runoff coefficient may indicate the amount of water flowing from a particular precipitation, and may reflect the impact of natural geomorphological elements on the flow. In addition, flow coefficients are useful for comparison with other

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watersheds, in order to understand how different landscapes transform precipitation into rainfall events (Che et al., 2018; Blume et al. 2007)

One of the most important factors in the evaluation and determination of the runoff coefficient is precipitation, which may refer to an isolated rainfall, or to a time interval, in which several rains occurred (Júnior, 2015). It may vary with the magnitude of the precipitation, because as the precipitation increases, the initial losses and the infiltration capacity are met. Thus, the runoff increases, resulting in a higher flow coefficient (Tucci, 2000a). However, in addition to precipitation characteristics, such as intensity, duration and distribution, specific physical aspects of watersheds affect the occurrence and volume of the runoff, such as soil type, vegetation, slope, contribution area and permeability. The permeability of the watershed is related to its ability to absorb water, that is, the greater the occurrence of permeable surfaces, the greater the chance of water infiltrating and reducing the volume of rainfall drained superficially (Wang et al., 2010; Park et al., 2014; Radecki-Pawlik et al., 2014). Soil moisture is also crucial for the control of hydrological processes, especially in the generation of surface runoff. In the early period of the rainy event, much of the precipitation infiltrates the soil, and in the course of rain, the soil reaches its saturation point. After that, all surplus will be superficially drained, a volume that can be mathematically determined by the runoff coefficient (Bagarello et al., 2018; Richardson & Amankwatia, 2018).

Therefore, the runoff coefficient can vary according to the characteristics of the terrain surface cover, of the physical characteristics and antecedent moisture, and of the different types of soils found in a watershed (Nunes et al., 2011).

It can be estimated using tables in which the runoff coefficient is related to the nature of the surface where it occurs. According to Lallam et al., (2018), the effective study of the coefficient is a very complex operation, due to the high number of variables that affect it. This means that the flow coefficients reported in the literature generally transmit less information than necessary (Blume *et al*., 2007), and therefore their values, when tabulated as if they were constant, may not correspond to reality.

There are still few studies on flow coefficient values obtained from rainfall and flow data in catchment areas. Given this context, this study had as objective to analyze extreme events of precipitation and the corresponding flows in catchments with different uses of land and soils, to obtain values of experimental coefficients of flow and compare them with the tabulated values. We separated the direct runoff from the base flow using

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digital filters. Thus, from the relation between surface runoff volume and precipitated volume, we determined the runoff coefficients for different rainfall-flow events.

2. MATERIAL AND METHODS

2.1 Areas of study

This study was developed from knowledge on rainfall and flow data. For this purpose, we selected monitored catchments with different land uses and cover located in São Paulo, southwestern region of Brazil (Figure 1).

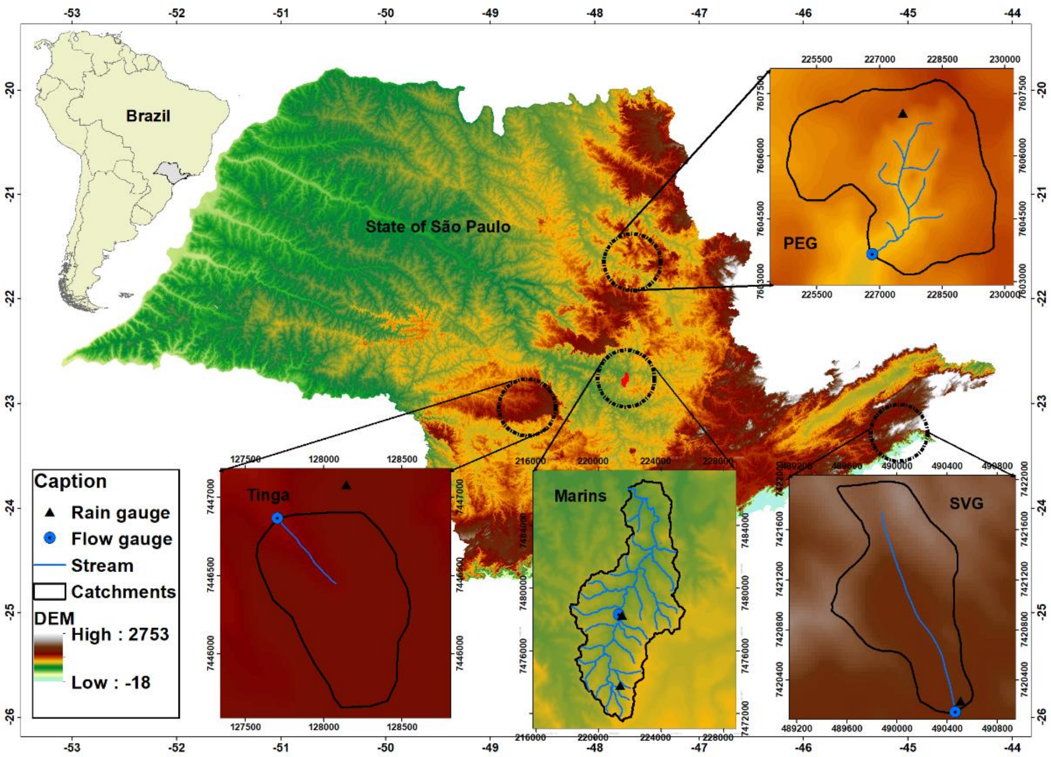

Figure 1 – Location map of experimental catchments located in the State of São Paulo, Brazil.

2.2 Tinga catchment

Tinga catchment is located in the Experimental Station of the Department of Forest Sciences of the Escola Superior de Agricultura "Luiz de Queiroz" School of Agriculture – ESALQ/USP, in the city of Itatinga. It has 83.57 ha of area. The dominant relief in the area (Pessotti, 1994) is smooth wavy, consisting of planed tops and slopes of rectilinear or convex forms. In lesser extent, there is the wavy relief, with slope between 10% and 15% and ramps of rectilinear shape, marked by the absence of flat tops. The drainage network is of low density, with rounded headwaters, from closed to open valleys, and restricted alluvial plain.

According to the Köppen classification, the climate is *Cfa*, i.e. humid mesothermal, with no defined dry season. The rainiest quarter corresponds to the months from December to February and the driest period to the months of May to August (Pessotti, 1994). The soil of Tinga catchment was classified as red latosol. The land cover of the catchment is predominantly *Eucalyptus saligna*. Along the creek there is a ciliary forest totaling 7.6 ha. Table 1 shows the land use classes in the Tinga catchment.

Table 1. Use and occupation of land in the Tinga catchment.

Usage classes	Area (ha)	Area (%)
Acacia	0.61	0.73
Araucaria	0.93	1.12
Carreador	4.44	5.31
Eucalyptus	65.96	78.94
Pinus	4.38	5.24
Native vegetation	7.25	8.67
Total	83.57	100

2.3 Pé de Gigante catchment (PEG)

The experimental PEG catchment underwent hydrological and micrometeorological monitoring and has an area of 15.6 km^2. It is located in the Vassununga Park, of the Institute of Forestry of the State of São Paulo. The area consists mostly of restricted cerrado, besides other physiognomies of cerrado and a small area with deciduous forest. The region is characterized by a differentiated relief that ranges from wide, medium and small hills, morrotes and residual hills, even escarpments, besides fluvial plains with predominance of smooth reliefs and low slopes (0 to 10%) (Bruno, 2009). The *Köppen* climatic classification of the experimental area is *Cwa*, with average monthly temperatures ranging from 17.6°C to 23.5°C and the average annual rainfall equal to 1,478 mm. The rainy season occurs between September to April, and the dry season between May to August (Bruno, 2009). The PEG catchment soil was classified as a red neosol. These are deep, porous and well-drained soils with moderate to weak A horizon and medium texture, presenting good physical characteristics for the root development of plants (Batalha, 1997). High levels of sand provide this soil with a good rooting ability in its physical aspects, but a low water retention capacity. Due to the relief to which they are associated and to the low degree of cohesion between

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particles, which occurs due to the low clay content, these soils are highly susceptible to natural erosion (Bruno, 2009).

2.4 Santa Virgínia catchment (SVG)

The Santa Cruz catchment (SVG) is located in the Serra do Mar State Park (PESM). Serra do Mar is a region of escarpment relief with typical plateau border, leveled by the top at altitudes from 800 to 1200 m, predominantly covered by dense ombrophilous forest (Freitas, 2012). In this region, the relief has strong slopes (24 to 37°). The predominant types of soils in the region are Red-Yellow Latosol, Cambisol, and litholic Neosol (Radambrasil, 1983). According to the Köppen classification, the climate is *Cwa* (köeppen, 1948). It has annual precipitation between 2,500 mm (east and west sector in the lowland, with superhumid tropical climate) and 1,500 mm (central sector, towards the plateau, with subhumid tropical climate). The average annual temperature varies from 22.5°C on the coast (from 19°C in winter to 25°C in summer) (Scardua, 1994).

2.5 Marins catchment (BHRM)

The Marins catchment is located in the municipality of Piracicaba, State of São Paulo, with an approximate area of 5,973 ha. The Marins catchment is of great socioeconomic and environmental importance for the region. The water resources coming from this catchment are used to irrigate most of the vegetables that supply the city and region, among other uses (Casagrande, 2005).

According to the *Köppen* classification, the climate is *Cwa* of mesothermic type, i.e. humid subtropical with drought in winter, whose rains of the driest month do not reach 30 mm and the temperature of the hottest month is higher than 22°C, while that of the coldest month is below 18°C (Machado & Vettorazzi, 2003). The precipitation and flow data are from two rain gauges and the hydrosedimentometric station installed in the catchment in 1999, under the responsibility of the Department of Water and Electricity (DAEE) and the Technology Center of Water Resources (CTH)/USP. One of the rain gauges (D4118r) was installed in the upper portion of the watershed at coordinates (UTM) 221379 and 7473744 m. The other pluviograph (D4116r) was installed near the hydrosedimentometric station, at coordinates (UTM) 221497 and 7478241 m. The contributory catchments until the post has approximately 22 km^2 (2200 ha) (Machado, 2002). The land is predominantly used for cultivation of sugarcane and pasture (Table 2). In the Marins catchment, the predominant soils are Litholic Neosols and Red-Yellow Argisols, with 58 and 42%, respectively (Table 3).

Table 2. Land use and occupation in the area of the Marins catchment.

Usage classes	Area (ha)	Area (%)
Reforestation	1.81	0.08
Sugarcane	1488.81	67.62
Pasture	481.20	21.85
Native vegetation	230.03	10.45
Total	2201.85	100

Table 3. Types of soil in the Ribeirão dos Marins catchment area.

Pedology	Area (ha)	Area (%)
Red-Yellow Latosols	18.55	0.84
Litholic Neosols	1267.07	57.51
Red-Yellow Argisols	917.45	41.64
Total	2203.07	100

2.6 METHODS

Based on data from the pluviographs installed in the catchments, we selected and analyzed extreme precipitation events – with potential for generation of surface runoff – and their respective flows with the objective of separating in the hidrograph the surface runoff volume from the base volume. Separating the direct runoff from base flow is a procedure that allows understanding the magnitude and the dynamics of the discharge of groundwater and the processes of direct runoff in watersheds (Brodie & Hostetler, 2005). It also allows analyzing the influence of several factors on the base flow and direct runoff. For example, the analysis of the influence of adopting practices for water and soil conservation in the reduction of flow peaks and in the increase of the minimum flows in periods of drought (Miranda et al., 2014; Vasconcelos et al., 2013). There are some methods for separation of flows, such as chemical analyses of certain substances identified as tracers, methods that are based on curve fittings through graphical analysis of hydrographs and digital filters of physical basis. We used the digital filter method proposed by Arnold (1999).

The digital filter technique developed by Arnold (1999) was originally used in the analysis and processing of signals to separate those of high frequency from those of low frequency. In this method, high frequency waves can be associated with the direct runoff and low frequency waves can be associated with the base flow(Lim *et al.*, 2005). The sum of both frequencies would correspond to the total flow of the hydrograph.

Although the technique has no actual physical basis, it is objective and reproducible (Arnold *et al*., 1995), this automated digital filter technique can be suitably compared to the estimates measured in the field.

The filter equation is:

$$q_t = \beta\, q_{t-1} + (1+\beta)/2 * (Q_t - Q_{t-1}) \quad (1)$$

Where q_t is the filtered surface flow (rapid response) in time *t* (one day), Q is the original flow and β is the filter parameter (0.925). The value of 0.925 was determined by Nathan & Mcmahon (1990) and Arnold et al. (1995) to give realistic results when compared with manual separation techniques. The base flow,b_t, is calculated with the following equation:

$$b_t = Q_t - q_t \quad (2)$$

The calculation of the surface runoff coefficient (C), relative to a rainfall event, was carried out by knowing the total volume flowed through the separation between this and base volume, using the digital filter, and the total precipitated on the basin, according to the relation below:

$$C = Ves/Vp \quad (3)$$

Where, C – Coefficient of flow; Ves – surface runoff volume; Vp – precipitated volume.

3. RESULTS AND DISCUSSION

After analyzing the rainfall-flow data at different seasons and selecting flood events from the Tinga, Pé de Gigante, Santa Virgínia and Marins catchments with digital filter, we found a variation of the values of the runoff coefficient between the rainfall-flow events selected and also different from the tabulated values.

Table 4 shows the values for experimental surface runoff coefficients. These coefficients (C_1-C_6) represent the data obtained in different dates and years* and the C_T is the tabled runoff coefficient (Tucci, 2000b). The values of C (Tinga – C5= 0.024; PEG – C2= 0.038; SVG – C6= 0.0003; BHRM – C3= 0.36) were obtained from the analysis of two consecutive precipitation events, the others were obtained from isolated events. The values were higher than the C values generated in the hydrograms that present an isolated precipitation event. This is because, after a precipitation event, the soil is already saturated or partially saturated, that is, the increase in soil moisture also increases the C value after the second precipitation event.

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Table 4. Calculated runoff coefficients of the study areas and their respective tabulated coefficients (C_T).

	C_1	C_2	C_3	C_4	C_5	C_6	C_T
Tinga	0.01	0.007	0.008	0.007	0.024	0.008	0.39
PEG	0.012	0.038	0.033	0.011	0.02	0.015	0.35
SVG	0.0001	0.0001	0.00015	0.0001	0.00009	0.0003	0.25
BHRM	0.30	0.21	0.36	0.13	0.06	0.15	0.31

Dates* Tinga – C_1: 07/01/2011 – C_2: 10 and 11/01/2011 – C_3: 27/01/2011 – C_4: 12/03/2011 – C_5: 12/04/2011 – C_6: 27 and 28/04/2011. PEG – C_1: 18 and 19/01/2012 – C_2: 17 and 18/01/2012 – C_3: 21/03/2013 – C_4: 17 and 18/09/2013 – C_5: 02 and 03/10/2013 – C_6: 28 and 2/12/2013. SVG – C_1: 06/01/2011 – C_2: 09/01/2011 – C_3: 11/01/2011 – C_4: 12 and 13/01/2011 – C_5: 14/02/2011 – C_6: 28/02/2011. BHRM – C_1: 08 and 08/01/1999 – C_2: 26 and 27/01/1999 – C_3: 01, 02 and 03/02/1999 – C_4: 21/02/2000 – C_5: 07 e 08/01/2000 – C_6: 26 and 27/03/2000.

Catchments with larger areas – BHRM (2200 ha) and PEG (1560 ha) – presented higher runoff coefficients than SGC (120.5ha) and Tinga (83.57ha), with smaller areas of contribution. This result is not always expected, because watersheds with larger areas tend to have greater water infiltration in the soil, since they are generally flatter regions (Gomi et al., 2008). According to Lemma et al., 2018, only the basin size is not a determining factor as an indicator of high or low runoff coefficients, and other characteristics of the basin have to be considered, such as slope, soil type and use and occupation of land. Surface characteristics of watersheds are more impacting in C values than its area of contribution (Merz et al., 2006). To analyze each of the watershed is important because several factors, such as climate, rainfall, relief, soils, geology and land use of the watershed, besides the impact of human activities, influence its hydrological behavior.

3.1 Tinga catchment

From the Tinga catchment we selected a sequence of hydrographs and precipitation with different types of behavior from 2011. Table 5 and Figure 2 show the hydrographs and precipitations that occurred in each event and the values of runoff coefficients. Figures 2a and 2c show the events in which the direct runoff was greater than the base flow, as there were more intense rains and consequently increased surface runoff. For less intense rains the tendency is that most of the water volume infiltrates in soils, especially in those occupied with eucalyptus (infiltration rate > rainfall intensity) (Zuquette & Palmai, 2006). This occurred in the hydrograph of Figures 2b, 2d, 2e and 2f. In the less intense precipitation events, the base flow was greater than the surface runoff. Figure 2f shows the hydrograph resulting from the analysis of two consecutive precipitation events. For analysis, in which two precipitation events occur in sequence, the C value was 0.024 (Table 5) higher than the C values of the other hydrographs that were analyzed in isolation.

In the observed hydrographs, the base flow predominated. The exception was two events, in which the direct runoff predominated. There was little variation in the runoff coefficient values for this catchment, possibly due to the uniformity of land use and cover. The behavior of hydrographs and the response of the catchment to precipitation events were influenced by the use and occupation of the land, which is predominantly characterized by eucalyptus (78.94%) and native vegetation (8.67%) on Red Latosol soil. Latosols are one of the thirteen orders of soils according to the Brazilian Soil Classification System. These soils consist of a material that is mineral predominantly, very weathered, with a B-latossolic diagnostic horizon, with high infiltration capacity. They represent more than 50% of the Brazilian territory, being the most important order in agricultural terms (Neto & Loper, 2009).

Table 5. Percentage of the flows of hydrograph and C of Tinga catchment.

Runoff	2011					
	January			March	April	
	Days					
	7	10, 11	27	12	12	27, 28
	Percentage (%)					
Observed	100	100	100	100	100	100
Direct	52.0	47.2	56.8	49.2	37.3	29.6
Base	48.0	52.8	43.2	50.8	62.7	70.4
C	0.01	0.007	0.008	0.007	0.024	0.008

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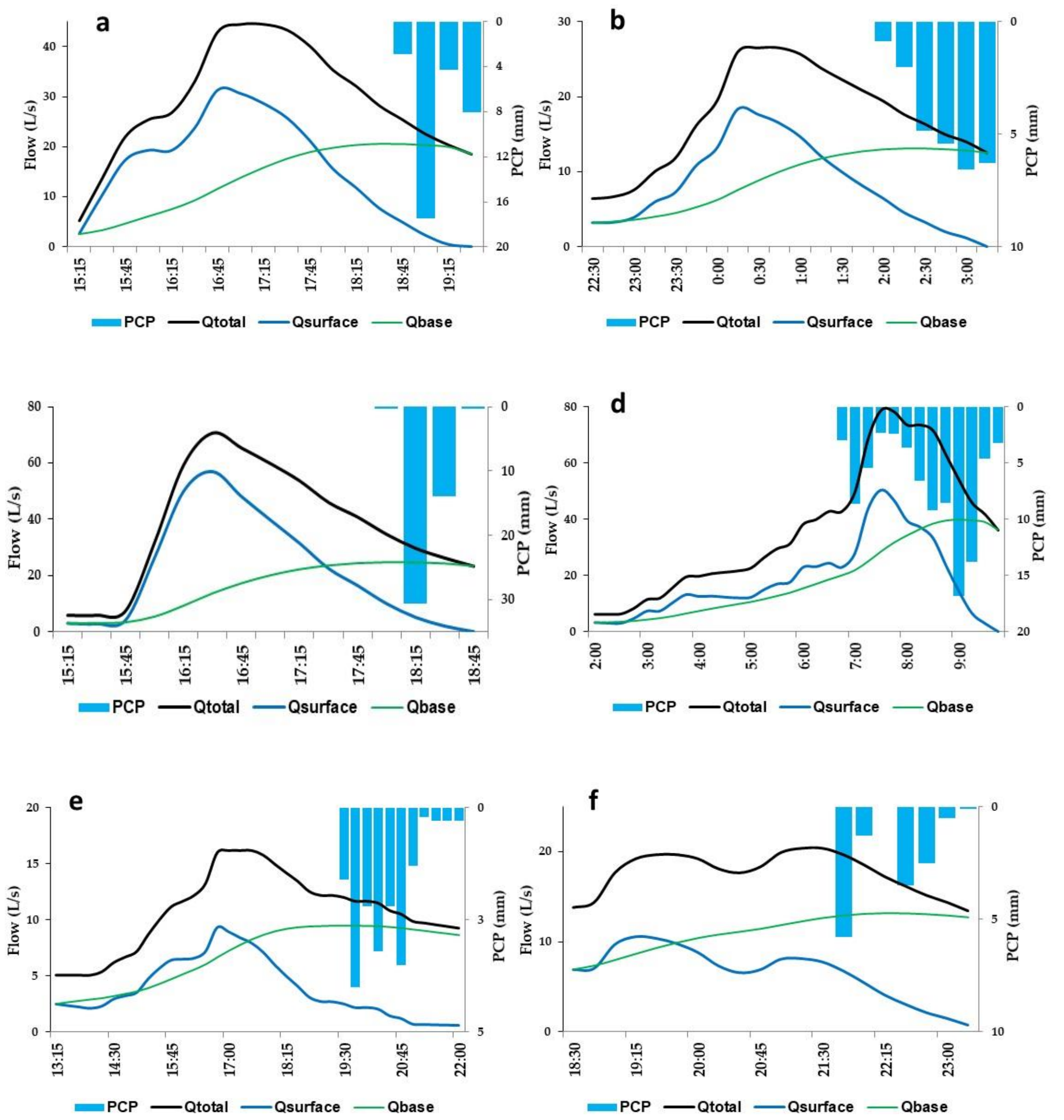

Figure 2. Hydrograph and precipitation (P) of Tinga catchment. January 7, 2011 (a), January 10 and 11, 2011 (b), January 27, 2011 (c), March 12, 2011 (d), April 12, 2011 (e), April 27 and 28, 2011 (f).

3.2 Pé de Gigante catchment (PEG)

Figure 3 shows the hydrograph of the events and Table 6, the runoff coefficient values obtained from the events analyzed between 2012-2013. In all events, the base flow was greater than the surface runoff. Considering that the type of land use and cover determines, in part, the hydrological behavior of a watershed, in this catchment the greatest cover of the earth is the Cerrado biome under Red Latosol, which has a medium, deep, porous and well drained texture, presenting good physical characteristics for root development of plants and water infiltration (Batalha, 1997). This condition favors water infiltration into the soil and generation of base flow. These results show the importance of the Cerrado biome associated to the soil of high infiltration capacity for the maintenance of the perenniality of rivers.

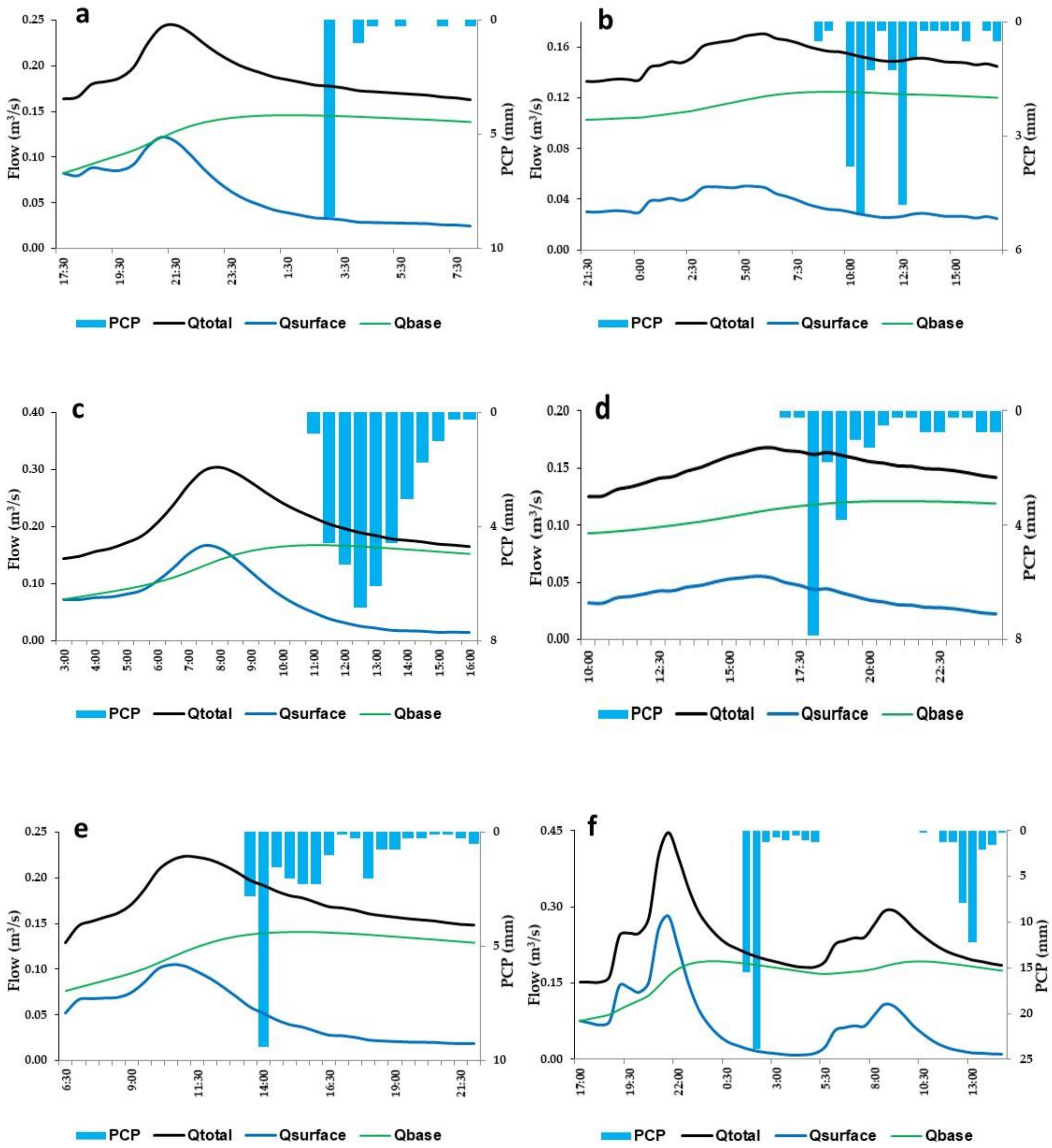

Figure 3. Hydrograph and precipitation (P) of PEG catchment. January 17 and 18, 2012 (a), October 18 and 19, 2012 (b), March 21, 2013 (c), September 17 and 18, 2013 (d), October 2 and 3, 2013 (e) December 28 and 29, 2013 (f).

Table 6. Percentage of flows of the hydrograph of PEG in 2012 and 2013.

Runoff	2012		2013			
	Jan	Oct	March	Sep	Oct	Dec
	Days					
	18, 19	17, 18	21	17, 18	2, 3	28, 29
	Percentage (%)					
Observed	100	100	100	100	100	100
Direct	30.7	23.8	34.6	25.8	25.8	29.8
Base	69.3	76.2	65.4	74.2	74.2	70.2
C	0.012	0.038	0.033	0.011	0.02	0.015

3.3 Santa Virgínia catchment (SVG)

Table 7 and Figure 4 show the hydrograph and C values for the SVG catchment, respectively. Some precipitation events analyzed occurred in very close periods of time. There was little variation in the runoff coefficient calculated for each event. From the six events analyzed, four presented greater base flow than surface runoff (Figures 4b, c, d, e). The rainfall intensity varied between 12.95 mm/h and 78.23 mm/h for the studied period. The hydrograph resulting from a complex precipitation event (Figure 4f) presented direct runoff (56.5%) greater than the base flow (43.5%). Data analysis that preceded this event confirmed the existence of a previous precipitation event, which increased the soil moisture and consequently the soil saturation.

The SVG catchment is characterized by native forest cover and clay soils with low activity and low base saturation in most of the first 100 cm of the B-horizon Haplic Cambisols (EMBRAPA, 2006). The forest cover intercepts rainwater, decreases its speed, protects and improves the soil hydrologic conditions due to the organic layer that accumulates on the surface (plant litter), allowing the infiltration process to occur slowly (Neary et al., 2009; Andréassian, 2004; Brown el al, 2005).

Table 7. Runoff percentage of the SVG hydrograph in 2011.

Runoff	2011					
	January		January		February	
	Days					
	06	09	11	12, 13	14	28
	Percentage (%)					
Observed	100	100	100	100	100	100
Direct	55.8	44.5	47.0	45.5	38.3	56.5
Base	44.2	55.5	53.0	54.5	61.7	43.5
C	0.0001	0.0001	0.00015	0.0001	0.00009	0.0003

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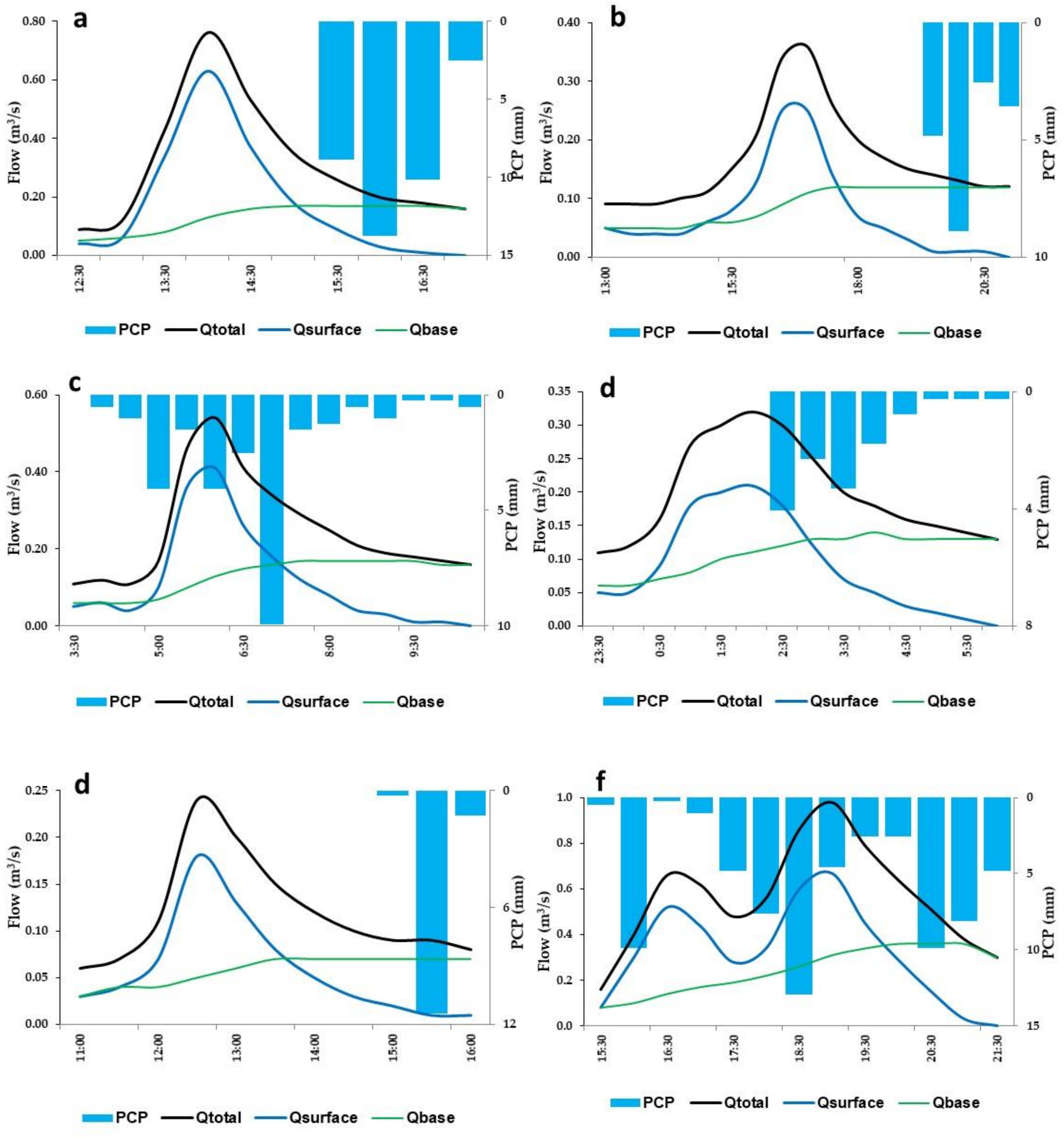

Figure 4. Hydrograph and precipitation (P) of SVG catchment. January 6, 2011 (a), January 9, 2011 (b), January 11, 2011 (c), January 12 and 13, 2011 (d), February 14, 2011 (e), February 28, 2011 (f).

3.4 Marins catchment (BHRM)

To calculate the mean precipitation of this watershed, which has two pluviometric stations, we used the Thiessen method. Hydrographs of the flood events based on flow and precipitation data, in 1999, during different months, are presented in Figure 5. In the corresponding period between January and February 1999 (Table 8), we observed that the mean of the medium direct runoff (64.87%) was higher than the mean of base flow (35.13%).

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Table 8. Runoff percentage of the hydrograph of BHRM in 1999 and 2000.

Runoff	1999				2000	
	January		February		January	March
	Days					
	08, 09	26, 27	01, 02, 03	21	07, 08	26, 27
	Percentage (%)					
Observed	100	100	100	100	100	100
Direct	63.4	69.8	64.3	62.0	23.9	30.2
Base	36.6	30.2	35.7	38.0	76.1	69.8
C	0.30	0.21	0.36	0.13	0.06	0.15

Lallam et al. (2018) quantified the influence of certain parameters on the runoff coefficient values of watersheds, and the vegetation cover is the most impacting one (vegetation density and degree of plant development). BHRM has a predominant coverage of sugarcane (approximately 70% of land use). The management of sugarcane has two distinct phases: first, furrowing of the soil for planting, and second, the maintenance over a period. During the furrowing phase the structures of the surface layer are destroyed, and the infiltration rate is very high. According to EMBRAPA (2018), the period between January and March is considered ideal for the growth of sugarcane, because it presents good conditions of temperature and humidity, guaranteeing the development of the gems (Fietz *et al*., 2015). The highest direct runoff observed occurred during this period because precipitation is not intercepted by any vegetation cover.

During this study period, the rainfall intensity ranged from 11.8 mm/h to 58.9 mm/h (Figures 5a-d). Castilho & Filho (2000) analyzed the interception of rainfalls in the sugarcane crop in a cultivation area in the city of Campinas, SP, located in the same climatic region (approximately 75 km of the BHRM), from February to December 1999. According to the author, in this period the total incident precipitation analyzed was 778.9 mm, of which 39.5% were intercepted and 60.5% represented the water depth in the soil. As sugarcane develops, the amount of precipitation intercepted by the vegetation cover represents an important part of the water balance. Tomasini *et al*., (2010) analyzed the effect of different soil cover in sugarcane cultivation area on the surface runoff in the erosion between the furrows. The authors verified that the effects of the sugarcane canopy and residue promoted the increase of the hydraulic roughness and the volumes of interception by the vegetation, reducing the water runoff. As previously mentioned, soil texture, moisture and compaction, vegetation management and cover, besides precipitation intensity can influence the runoff and consequently the runoff coefficient value. As direct runoff and base flow alternated in discharge formation (Figures 5a-f), different C values were expected for each period. Table 4 shows a variation between all experimental runoff coefficient values (between 0.13 and 0.36), in relation to the tabled runoff coefficient value (0.31).

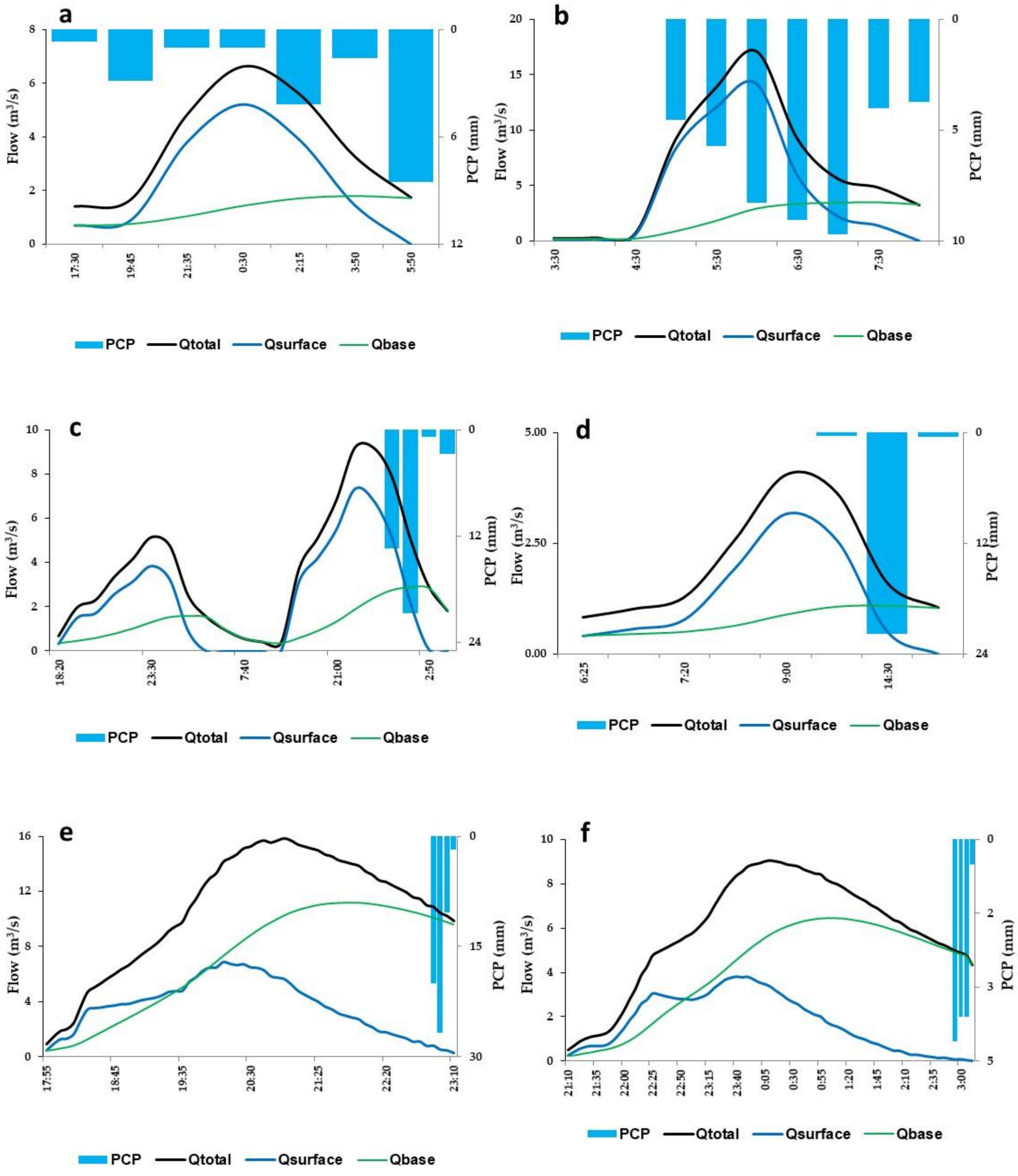

Figure 5. Hydrograph and precipitation (P) of BHRM. January 8 and 9, 1999 (a), January 26 and 27, 1999 (b), February 1, 2 and 3, 1999 (c), February 21, 1999 (d), January 7 and 8, 2000 (e), 26 and 27 March 2000 (f).

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4. CONCLUSIONS

We determined the runoff coefficients (C) in four experimental catchments, with different land and soil uses, using a digital filter for separating of the base flow from the surface runoff. From the relationship between surface runoff volume and precipitated volume, we determined the C values and compared them with the tabulated values. The values obtained in the experimental catchments were very different from each other and also from the tabulated values. In the catchments with original vegetation cover, such as the cerrado (PEG catchment) and Atlantic forest (SVG catchment), the runoff coefficient little varied among the events analyzed, different from the catchment where land use and occupation are predominantly agricultural (BHRM catchment). As the tabulated values were obtained in experimental plots, they do not translate reality, since each watershed has different characteristics. Direct runoff and water infiltration depend on geological, climatic and physiographic factors of the region, such as: watershed area, sharp slope and water-retentive depressions, soil type and moisture, and the quantity and intensity of precipitation, among others. The high correlation of runoff coefficients for land and soil use found in this study may be related to the effects size of the study area. In smaller areas, soil type and land use become more important, according to several plot-scale studies. Although the tabulated C values overestimated the values obtained in experimental catchments and the higher the C value, the lower the risk of the hydraulic work failing, care is required when choosing these values for estimating maximum discharge in engineering projects. As the runoff coefficient could not be determined in urban catchments due to lack of data, studies on these conditions should be conducted, considering the artificial modifications that tend to increase the peak discharge, such as soil sealing, urban drainage and river channelization.

REFERENCES

ANDRÉASSIAN, V., 2004. Water and forests: from historical controversy to scientific debate. Journal of Hydrology, 291: 1-27.

ARNOLD, J.G.; ALEEN, P.M. B., 1995. Automated Base Flow Separation and Recession Analysis Techniques.

ARNOLD, J.G., 1999. Automated Method's for estimating baseflow and Florida is highly dependent on ground water mates of baseflow and recharge.

BAGARELLO, V.; STEFANO, C.; VITO, F.; VICENZO, P. Comparing theoretically supported rainfall-runoff erosivity factors at the Sparacia (South Italy) experimental site. Hydrological Processes (Online), Chichester, v. 32, n. 4, p. 507-515, Feb 15 2018. https://doi.org/10.1002/hyp.11432

BATALHA, M.A., 1997. Análise da vegetação da ARIE Cerrado Pé de Gigante (Santa Rita do Passa Quatro, SP). Univ. Fed. São Paulo.

BEDIENT, P., HUBER, W., AND VIEUX, B. (2013). Hydrology and floodplain analysis, 5th Ed., Pearson Publishing, NJ.

BLUME, T., ERWIN, Z., BRONSTERT, A., 2007. Rainfall-runoff response, event-based runoff coefficients and hydrograph separation. Hydrol. Sci. J. 52, 843–862.

BRODIE, R.S.; HOSTETLER, S., 2005. A review of techniques for analysing baseflow from stream hydrographs. Proc. NZHS-IAH-NZSSS Conf. 28.

BROWN, A.E.; ZHANG, L.; McMAHON, T.; WESTERN, A.W.; VERTESSY, R.A., 2005. A review of paired catchment studies for determining change in water yield resulting from alterations in vegetation. Journal of Hydrology, 310: 28-61.

BRUNO, R.D., 2009. Balanço de água em microbacias de cerrado restrito e eucalipto: Um estudo de caso com medidas observacionais.

CASAGRANDE, C.A., 2005. Diagnóstico ambiental e análise temporal da adequabilidade do uso e cobertura do solo na Bacia do Ribeirão dos Marins, Piracicaba–SP.

CASTILHO, C. G.; FILHO, J.T., 2000. Interceptação de chuvas na cultura da cana-de-açúcar (Saccharum Officinarum ssp.). Eng. Agrícola.

CHE, D.; LIANG, A.; LI, X.; MA, B. Remote Sensing Assessment of Safety Risk of Iron Tailings Pond Based on Runoff Coefficient. Sensors 2018, 18, 4373. doi: 10.3390/s18124373

EMBRAPA, 2018. Plantio da cana-de-açúcar. https://www.agencia.cnptia.embrapa.br/gestor/cana-de-acucar/arvore/CONTAG01_33_711200516717.html

EMBRAPA, 2006. Sistema Brasileiro de classificação de solos. Embrapa Solos - Empres. Bras. Pesquisa. Agropecuária.

FIETZ, C.R.S.; COMUNELLO, C.; FLUMIGNSN, E.; DANILTON, L., 2015. Cana-de-Açúcar: Risco Climático para Plantios de Inverno na Região Sul de Mato Grosso do Sul. Comun. Técnico 209 1–9.

FREITAS, H.C., 2012. Energia Nuclear na Agricultura A influência dos transportes advectivos na estimativa do balanço de CO2 do ecossistema: Um estudo de caso para a mata atlântica com uso.

GOMI, T., SIDLE, R.C., MIYATA, S., KOSUGI, K., ONDA, Y. (2008). Dynamic runoff connectivity of overland flow on steep forested hill slopes: Scale effects and runoff transfer. Water Resources Research, 44, W08411. http://dx.doi.org/ 10.1029/2007WR005894.

JÚNIOR, A.R.B., 2015. Elementos de Hidrologia Aplicada - UFOP - Universidade Federal de Ouro Preto 92–155.

KÖEPPEN, W., 1948. Fundo de Cultura Econômica, México. KREBS.

LALLAM F., MEGNOUNIF A., GHENIM A.N. 2018. Estimating the runoff coefficient using the analytic hierarchy process. Journal of Water and Land Development. No. 38 p. 67–74. doi: 10.2478/jwld-2018-0043

LEMMA, T.M.; GESSESSE, G.D.; KASSA, A.K.; EDOSSA, D.C. Effect of spatial scale on runoff coefficient: Evidence from the Ethiopian highlands. Int. Soil Water Conserv. Res. 2018, 6, 289–296. doi: 10.1016/j.iswcr.2018.08.002

LIM, K. J.; ENGEL, B. A.; TANG, Z.; CHOI, J.; KIM, K. S.; MUTHUKRISHMAN, S.; TRIPATHY, D., 2005. Automated Web GIS based hydrograph analysis tool, WHAT. J. Am. Water Resour. Assoc. 41, 1407–1416.

MACHADO, R.E., 2002. Simulação de escoamento e de produção de sedimentos em uma microbacia hidrográfica utilizando técnicas de modelagem e geoprocessamento.

MACHADO, R.E., VETTORAZZI, C.A., 2003. Simulação da produção de sedimentos para a microbacia hidrográfica do Ribeirão dos Marins (SP). Rev. Bras. Ciência do Solo 27, 735–741.

MERZ, R., BLÖSCHL, G., PARAJKA, J. 2006. Spatio-temporal variability of event runoff coefficients. Journal of Hydrology, 331, 591–604. https://doi.org/10.1016/j.jhydrol.2006.06.008

MIRANDA, A. C. R.; MARTINEZ, M. A.; CECON, P.R., 2014. Métodos de separação dos escoamentos superficial direto e subterrâneo: Estudo de caso para a bacia do Rio das Velhas. RBRH - Rev. Bras. Recur. Hídricos 19, 169–181.

NATHAN, R. J.; MCMAHON, T.A., 1990. Evaluation of automated techniques for baseflow and recession analysis. Water Resour. Res. 26, 1465–1473.

NEARY, D. G.; ICE, G. G.; JACKSON, C.R., 2009. Linkages between forest soils and water quality and quantity. For. Ecol. Manage. 2269–2281.

NETO, P. J. C.; LOPER, E.W., 2009. Caracterização física do Latassolo Vermelho distrófico da fazenda Escola da fazu. Agronomy 21–26.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 18 July 2019 doi:10.20944/preprints201907.0208.v1

NUNES, F. G.; FIORI, A. P.; FIRPO, G., 2011. Estimativa de coeficientes de escoamento superficial na bacia hidrográfica do rio Atuba: Curitiba e região metropolitana - Paraná/ Brasil. Bol. Parana. Geociências 64, 27–39.

PARK, D. G; SANDOVAL, N.; LIN, W.; KIM, H.; CHO, Y. H.A case study: Evaluation of water storage capacity in permeable block pavement. KSCE Journal of Civil Engineering, Seoul, v. 18, n. 2, p. 514-520, 03 2014. https://doi.org/10.1007/s12205-014-0036-y

PESSOTTI, F.E.S., 1994. Levantamento detalhado dos solos do Horto de Itatinga. ESALQ - Esc. Super. Agric. ``Luiz Queiroz´´ - USP.

RADAMBRASIL. 1983. Projeto Radambrasil: levantamento de recursos naturais. IBGE. Rio de Janeiro.

RADECKI-PAWLIK, A.; WALEGA, A.; WOJKOWSKI, J.; PIJANOWSKI, J. Runoff formation in terms of changes in land use - Msciwojow water reservoir area/ Odplyw powierzchniowy w rejonie zbiornika wodnego Msciwojow w swietle planowanych zmian urbanistycznych. Journal of Water and Land Development, Raszyn, v. 23, n. 1, p. 3-10, 2014. doi: 10.1515/jwld-2014-0024

RICHARDSON, C.P.; AMANKWATIA, K. GIS-Based Analytic Hierarchy Process Approach to Watershed Vulnerability in Bernalillo County, New Mexico. Journal of Hydrologic Engineering, New York, v. 23, n. 5 05 2018. doi: 10.4236/jwarp.2019.112007

SCARDUA, F.P., 1994. Caracterização hidrológica de uma microbacia hidrográfica experimental da Estação Experimental de Ciências Florestais de Itatinga, ESALQ/USP. ESALQ - Esc. Super. Agric. ``Luiz Queiroz´´ - USP 93.

ŞEN, Z.; ATUNKAYNAK, A., 2006. A comparative fuzzy logic approach to runoff coefficient and runoff estimation. Hydrol. Process. 20, 1993–2009.

TOMASINI, B. A.; VITORINO, A. C. T.; GARBIATE, M. V.; SOUZA, C. M. A.; SOBRINHO, T.A., 2010. Infiltração de água no solo em áreas cultivadas com cana-de-açúcar sob diferentes sistemas de colheita e modelos de ajustes de equações de infiltração. Eng. Agrícola 30, 1060–1070.

TUCCI, C.E.M., 2000a. Coeficiente de escoamento e vazão máxima de bacias urbanas. RBRH - Rev. Bras. Recur. Hídricos 5, 61–68.

TUCCI, C.E.M. 2000b. (org.) Hidrologia – ciência e aplicação. Editora da Universidade, ABRH, Porto Alegre.

VASCONCELOS, V.; HADDAD, R.M., 2013. Quantificação de componentes de vazão por meio de filtros recursivos: Estudo de caso para a Bacia do Rio Paracatu (SF-7), Brasil. Rev. do Inst. Geociências - USP.

ZUQUETTE, L.V., PALMAI, J.B., 2006. Avaliação da taxa de infiltração e escoamento superficial dos arenitos da formação Botucatu. Rev. Bras. Geociências 36, 49–60.

WANG, D. C; WANG, L. C.; CHENG, K. Y.; LIN, J. D. Benefit Analysis of Permeable Pavement on Sidewalks. International Journal of Pavement Research and Technology, Jhongli City, v. 3, n. 4, p. 207-215, 07 2010. http://www.ijprt.org.tw/files/sample/V3N4%286%29.pdf