

TIME OF CONCENTRATION IN THE UFSC CAMPUS CATCHMENT, FLORIANÓPOLIS-SC (BRAZIL), CALCULATED WITH MORFOMETRIC AND HYDROLOGICAL METHODS

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ABSTRACT

The Federal University of Santa Catarina (UFSC) campus catchment (BC) with area of 4.078 km² is a typical urban catchment and is a part of the Itacorubi catchment which is the second largest one in the Santa Catarina Island, Brazil. Due to an intensified and disordered urbanization, the BC has been frequently suffering from floods. For reducing floods damages, the UFSC initiated the Hydrology Project (PHC) in the campus. With an installation of a meteorological station and a gauge, the PHC has been automatically executing the hydrological monitoring. Using the data obtained with this monitoring, the morphometric and hydrological calculation of the time of concentration (T_c) in the BC was carried out. For the former method, the formulas of Kirpich, Dooge, Carter, Federal Aviation Agency, and McCuen were used. While the mean T_c value among them was 31.8 min, the value obtained with the Formula of Dooge was larger than the others. For the hydrological method, only six precipitation events that occurred during the period of January to May, 2006, were analyzed. The mean T_c value with this method was 34 min. By treating these six events, the relations of T_c with the total precipitation, the maximum precipitation intensity, the precipitation duration, the mean precipitation intensity, and the mean discharge were analyzed. Just only with six events, the negative correlation with the mean precipitation intensity and the positive one with the duration were obtained. Though T_c varies with the precipitation intensity, its commonest value may be approximately between 30 min and 35 min. Then, if the Index of Efficiency of Operation is used, it can be said that the BC normally has flash floods. It implies a necessity of the establishment of the rapid alert system in the BC. The present study analyzed only six precipitation events. Furthermore, none of them had high precipitation intensity. To gain a better estimation of T_c in the BC, it will be necessary to analyze more events with high intensity for the future study of the PHC.

Key-words: Time of concentration; catchment morphometry; hydrological monitoring.

INTRODUCTION

Floods have been influencing on the human history. By analyzing the available data of the EM-DAT (Emergency Disasters Date Base), Goerl and Kobiyama (2005) showed the significant increase of the number of occurrences and the number of affected people in the world for the last decades. This increase may be caused strongly by the human activities (for examples, the intensified and disordered urbanization, hazard areas

occupation and deforestation). Plate (2002) affirmed that the pressure exerted by the population growth results in the exclusion of the poor people. These people have begun to live on flood plains. This type of problem is commonly observed in urban areas. Costa and Teuber (2001), with case study of the Rio de Janeiro state, mentioned that the floods are not inevitable but that the damages can be reduced.

According to Kobiyama et al. (2004) that analyzed the natural disasters database on Brazil for the period of 1948 to 2004, floods are the natural disasters that provoke human losses more in Brazil. The current situation of the Florianópolis city whose major part is the Santa Catarina Island is not an exception. The second largest catchment in this island, i.e., the Itacorubi catchment (approximately 25 km²) is still more anxious because of disordered and accelerated urbanization (Bez et al., 1999).

The Federal University of Santa Catarina (UFSC) is located at the central region of the Itacorubi catchment. Because of both the scientific interest and the social-environmental responsibility, the UFSC initiated the Hydrology Project (PHC) in its campus in 1981. Various hydrological studies have been carried out since 1981.

In 2004, a gauge and a meteorological station were installed inside the campus, which makes the short-interval hydrological monitoring possible (Grison, 2005). Thus, an experimental catchment was established and called the campus catchment (BC) of UFSC. With this hydrological monitoring activity, the Hydrology Laboratory (LABHIDRO) of UFSC was created. To advance hydrological study in the BC, the visualization of the data obtained with the automatic hydrological monitoring at the above-mentioned stations and its data-liberalization on the site of the LABHIDRO (www.labhidro.ufsc.br) have been performed (Kobiyama, 2005). These works have significantly contributed to the scientific researches as well as the university education.

As the main objective of the PHC is to reduce natural disasters caused by floods, it is still necessary to realize various studies. That is why the objective of the present study that is a part of the PHC was to morphometrically and hydrologically calculate the time of concentration (T_c) of the BC. According to Singh (1976), Mulvany (1850) was the first publication that mentioned the T_c concept. By relating with the maximum discharge, Mulvany (1850) defined T_c as the time necessary for rain that falls at the longest place from the catchment mouth, to flow out at the mouth. Singh (1976) showed that the spatial and temporal characteristics of precipitation as well as the morphometric (or geometric) characteristics of the catchment influence on the T_c value, and mentioned that the precipitation duration possesses a definite influence on it.

Time parameters are very important in water resources management, in terms of the structural and non- structural measures. Among them, T_c is most frequently used (McCuen et al., 1984). Because of such importance of this parameter, a lot of formulas to estimate it have been proposed. Silveira (2005) evaluated the performance of 23 formulas for rural and urban catchments and showed that the performance of these formulas for rural catchments is better than that for urban ones. It implies the larger difficulty to estimate T_c for urban catchments than rural ones. Then, the present study applied various formulas to verify the T_c value in the BC and discussed influences of some precipitation characteristics on T_c .

STUDY AREA

The UFSC Campus catchment - BC (approximately 4 km²) is a part of the Itacorubi catchment (Figure 1). Its main stream channel is situated from its head (332 m) to the mouth (3 m), being tributary to the Três Córregos River that reaches a bay. In the UFSC campus, this channel is called the Meio river. The BC consists of two geological units: the crystalline complex represented by granites and granodiorites and the Quaternary sedimentary deposits (Sierra and Ledo, 1998). Though most of the vegetation is at the secondary stage, the remainings of the Tropical Ombrophilous Forest at the primary condition can be encountered at various locations. Because of the actual land-uses, this catchment is considered an urban one.

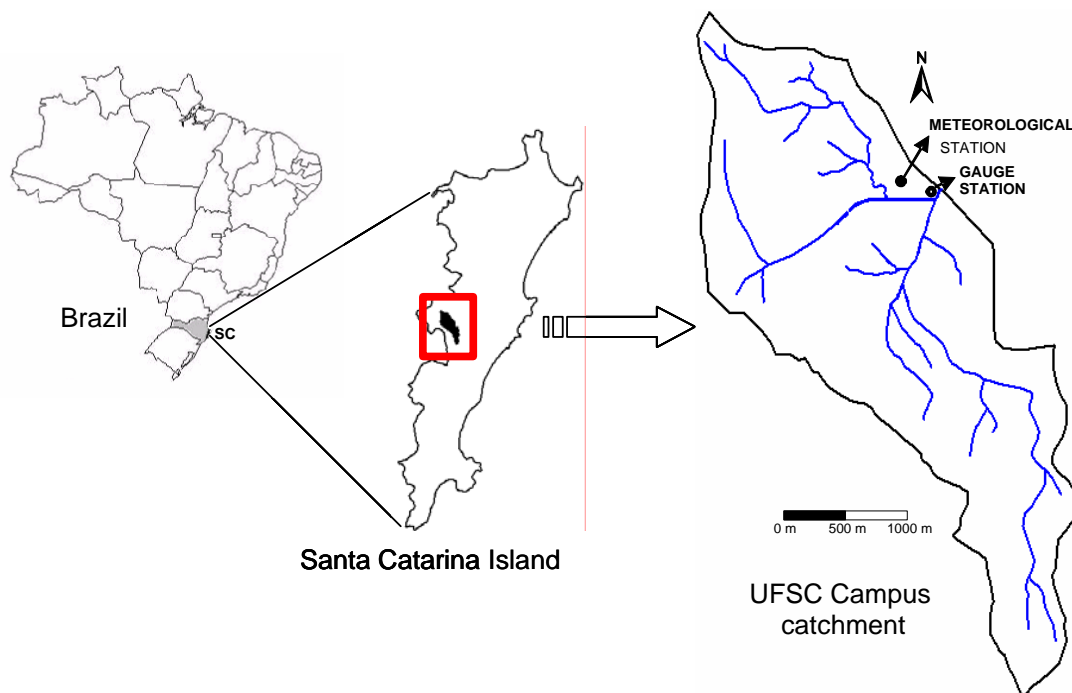


Figure 1 – Locality of the UFSC Campus Catchment

The mean monthly air humidity is about 82%. The mean annual isolation is 2026 hours which are 46% of the total potential. The mean potential evapotranspiration is 1019 mm/year, varying between months (107 mm in December and 65 mm in June) (Sierra and Ledo, 1998).

Recently a meteorological station and a gauge were installed in front of the UFSC Central Library, and at the left edge of the Meio River in front of the Health Sciences Center (CCS/UFSC), respectively. Some hydrological parameters are monitored every minute and transmitted to a computer at the LABHIDRO. The data are available in the internet and renewed every 5 minutes in its site.

METHODS

Morphometric characterization of the catchment

By using a map (1:10.000 scale), the area (A) in km^2 , the river length (L) in km, the catchment relief (H) in km and the slope ($S = H/L$) were measured.

Estimation of time of concentration

The formulas of Kirpich, Dooge, Carter, Federal Aviation Agency, and McCuen were used to calculate T_c (Table 1). The first three ones require only morphometric parameters for its calculation. In the Federal Aviation Agency formula, C is the surface runoff coefficient of the Rational Method. According to Silveira (2005), C is 0.9 for the urban catchments. In the McCuen formula, i is the maximum precipitation intensity in mm/h for the return period of 2 years.

Table 1 - Formulas to estimate the T_c in minutes.

Name	Formula	Source
Kirpich	$T_c = 3.989 \cdot \frac{L^{0.77}}{S^{0.385}}$	Kirpich (1940)
Dooge	$T_c = 21.88 \cdot \frac{A^{0.41}}{S^{0.17}}$	Porto (1995)
Carter	$T_c = 5.862 \cdot \frac{L^{0.6}}{S^{0.3}}$	Carter (1961)
Federal Aviation Agency	$T_c = 22.73 \cdot (1.1 - C) \frac{L^{0.5}}{S^{0.33}}$	Federal Aviation Agency (1970)
McCuen	$T_c = \frac{135}{i^{0.7164}} \cdot \frac{L^{0.5552}}{S^{0.2070}}$	McCuen et al. (1984)

Although the T_c concept was defined initially by Mulvany (1850), it can be defined in other ways. For example, T_c is the time difference between the end of the effective precipitation and the end of the direct runoff (McCuen et al., 1984; Silveira, 2005). Since it is difficult to determine the effective precipitation, the present study used the end of the precipitation event. The end of the direct runoff was determined with use of the semi-logarithm graph of the total discharge against the time. In this graph, two discontinuous straight lines were drawn through visual observation of the curve trend. Their intersection point determined the end of the direct runoff. Here this procedure is called a hydrological method with use of hyetograph and hydrograph.

RESULTS AND DISCUSSION

With the catchment morphometric analysis, it was obtained that $A = 4.078 \text{ km}^2$, $L = 3.55 \text{ km}$, $H = 0.329 \text{ km}$, and $S = 0.0927$. These values were used to calculate the T_c value with the five formulas shown in Table 1.

With use of the Formulas of Kirpich, Dooge, the Carter, Federal Aviation Agency, and McCuen, the values of T_c are of 26.4 min, 58.3 min, 25.6 min, 18.8 min, and 29.6 min, respectively. For the McCuen formula, the adopted value of i was 44.2 mm/h. This is the largest value observed at the meteorological station during the last two years, and was registered on January 31st, 2006 at night. The mean T_c value among the five formulas is 31.8 min. The value gained with the Dooge formula, which is the unique formula that uses a area, is largest among all. If the Dooge formula is not used, the mean T_c value becomes 25.1 min.

Figure 2 shows an example of the visual determination of the end of the direct runoff at the mouth on March 2nd, 2006. After this determination, T_c was calculated on a graph of the set of hyetograph and hydrograph (Figure 3).

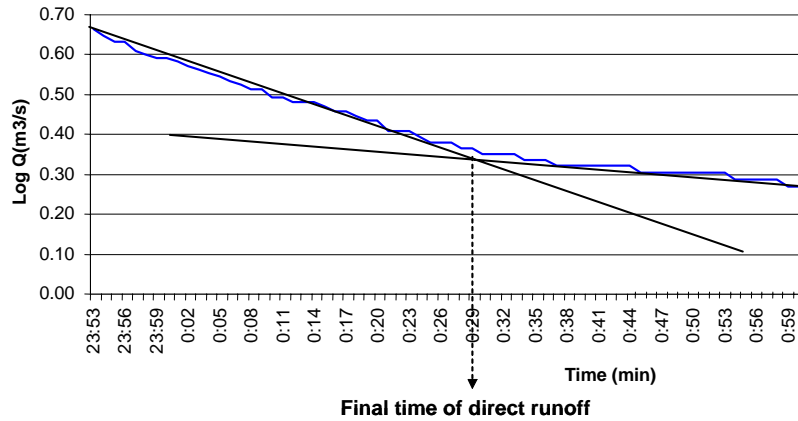


Figure 2 - Visual determination of the end of the direct runoff for the precipitation event on March 2nd, 2006.

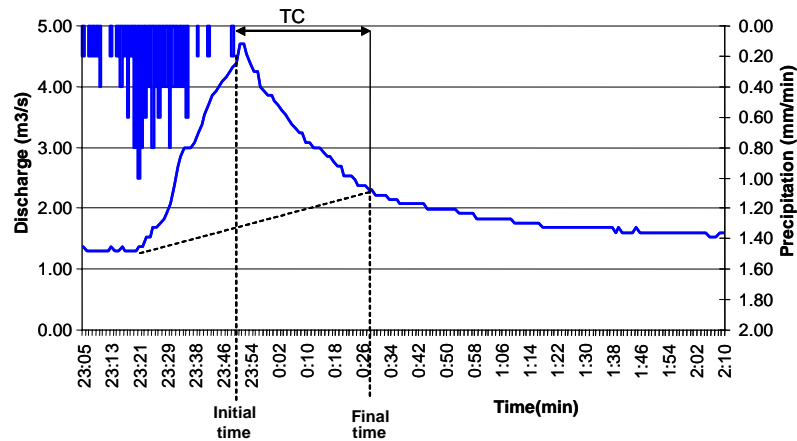


Figure 3 – Hydrological estimation of T_c for the precipitation event on March 2nd, 2006.

Table 2 shows the results obtained with the hydrological method. Here, the mean discharge (Q_{mean}) is defined as an arithmetic mean value between the discharge at the hydrograph peak and that at the end of the direct runoff. The mean T_c value obtained with the hydrological method is 34 min.

Table 2 - Time of concentration (T_c) obtained with the hydrological method, total precipitation (P_t), maximum precipitation intensity (I_{max}), precipitation duration (D), mean intensity (P_t/D), and mean discharge (Q_{mean}) for six precipitation events.

Evento (data)	T_c (min)	P_t (mm)	I_{max} (mm/min)	D (min)	P_t/D (mm/min)	Q_{mean} (m ³ /s)
Jan 24, 2006	35	7.4	1.4	74	0.1	2.805
Jan 25, 2006	34	11.6	0.8	62	0.19	3.740
Mar 2, 2006	36	13.0	1.0	47	0.28	3.505
Mar 4, 2006	32	14.8	2.2	15	0.99	5.135
Apr 7, 2006	31	9.8	1.2	17	0.58	3.695
May 8, 2006	36	11.6	1.6	40	0.29	2.995

Through the correlation analysis, McCuen et al. (1984) showed that the most and the least important parameters for determining T_c were i and S , respectively, and that the larger intensity, the smaller T_c . When a steady state occurs at the equilibrium time (T_e), T_c is equal to T_e (Saghafian and Julien, 1995). The same authors theoretically demonstrated that T_e is inversely proportional to the high precipitation intensity raised to the power 0.4. Though Table 2 shows the tendency in which T_c decreased with the increase of the maximum precipitation intensity (I_{max}), a very low correlation between T_c and I_{max} was obtained in the present study. With only six precipitation events, it is very difficult to conclude if the correlation between them exists or not. The correlation between T_c and the total precipitation (P_t) was very low, too.

Figure 4 shows that there is the correction between T_c and the mean intensity (P_t/D). In this case, the value of potential is of -0.0521 .

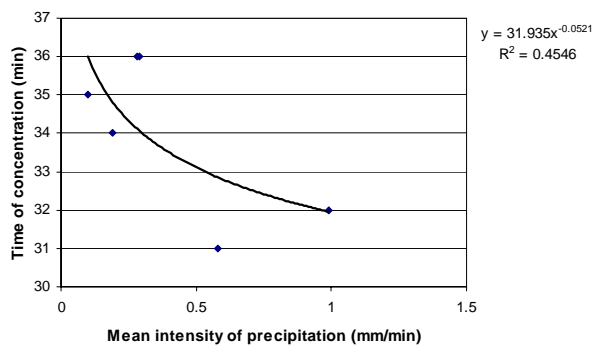


Figure 4 – Relation between the time of concentration and the mean precipitation intensity.

The simple theory indicates that T_c is inversely proportional to the flow velocity, consequently to the discharge. It can be confirmed with Figure 5. Figure 6 shows a positive correlation between the T_c and the precipitation duration (D), affirming the theoretical manifestation by Singh (1976), i.e., the D possesses a definite influence on T_c .

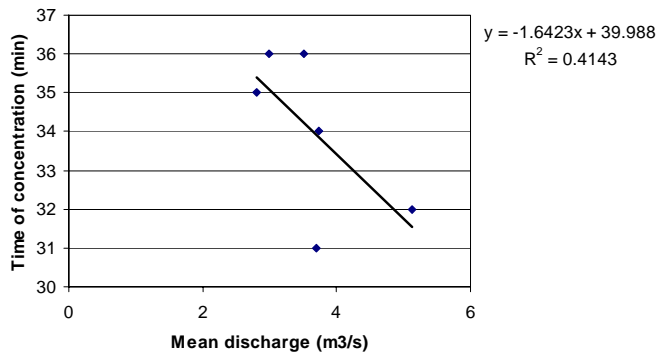


Figure 5 - Relation between the time of concentration and the mean discharge

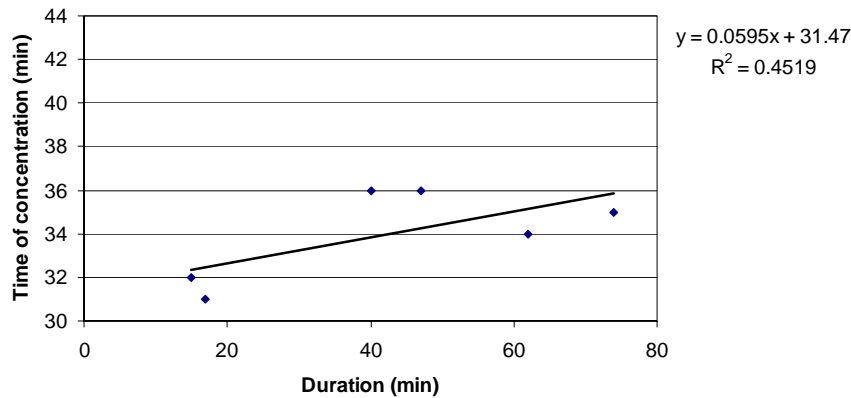


Figure 6 – Relation between the time of concentration and the duration of the precipitation

Thus, the mean values of T_c obtained with the morphometric and hydrological methods are 31.8 min and 34 min, respectively. This result where the latter method estimated T_c a few more could occur because of the fact that the events analyzed in the present study did not have strong precipitation intensity. According to Silva et al. (2005), the maximum intensity registered in Florianópolis city during the period of 1995 to 2001 was 73.6 mm/h which occurred on December 24th, 1995. This precipitation event generated one of the biggest natural disasters in the city. If the value of 73.6 mm/h is used for i of the McCuen formula, T_c is 20.5 min. It implies that the future study with the hydrological methods will probably produce the smaller value of T_c . However, on this moment it can be said that, even though the T_c values vary with the precipitation intensity, the commonest value may be between 30 and 35 minutes in the BC.

To differentiate floods and flash floods, Kobiyama et al. (2006) proposed the Operation Efficiency Index (E) that is the ratio of T_c on the operational time for the institution-community system to respond against flood disasters. The same authors mentioned that when the E value is inferior to one, flash flood occurs. It is quite difficult to have the operational time for the institution-community system to respond against floods, shorter than one hour in Florianópolis. Then, in case of the UFSC campus catchment, E is normally inferior to one, which implies that flash floods occur in this catchment. Therefore, the communities in this catchment must require monitoring centers, weather forecasting and alert system.

CONCLUSIONS

The UFSC campus catchment (BC) with area of 4.078 km² is a typical urban catchment and is a part of the Itacorubi catchment which is the second largest one in the Santa Catarina Island. Due to an intensified and disordered urbanization, the BC has been suffering from floods. In order to reduce floods damages, the UFSC initiated the Hydrology Project (PHC) in the BC. With an installation of a meteorological station and a gauge, the PHC recently initiated the automatic hydrological monitoring.

Using the data obtained with this monitoring, the present study calculated the time of concentration (T_c) of the BC with the morphometric and hydrological methods. In the former method, the Formulas of Kirpich, Dooge, Carter, Federal Aviation Agency, and McCuen were used. While the mean value of T_c among them was 31.8 min, the value obtained with the Formula of Dooge was larger than the others.

For the hydrological estimation, only six precipitation events that occurred during the period of January to May, 2006, were analyzed. The mean T_c value with this method was 34 min. Using these six events, the relations of T_c with the total precipitation, the maximum precipitation intensity, the precipitation, the mean precipitation intensity, and the mean discharge were analyzed. Though only six events were treated, the negative correlation with the mean precipitation intensity and the positive one with the duration were obtained. Though T_c varies with the precipitation intensity, its commonest value can be approximately between 30 min and 35 min.

Then, if the Index of Efficiency of Operation is used, it can be said that the BC possesses flash floods. It implies a necessity of the establishment of the rapid alert system.

The present study analyzed only six precipitation events. This is a very small number for events analysis, and none of them had high precipitation intensity. To gain a better calculation of T_c in the BC, it will be necessary to analyze more events with high precipitation intensity for the future study of the PHC.

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