# ESTIMATION ON TIME OF CONCENTRATION OF OVERLAND FLOW IN WATERSHEDS: A REVIEW

**ARTICLE** · JANUARY 2014

**7 AUTHORS**, INCLUDING:


Isabel Kaufmann de Almeida
Universidade Federal de Mato Grosso do Sul
**15** PUBLICATIONS **0** CITATIONS
SEE PROFILE


Jamil Alexandre Ayach Anache
University of São Paulo
**13** PUBLICATIONS **2** CITATIONS
SEE PROFILE


Jorge Luiz Steffen
Universidade Federal de Mato Grosso do Sul
**18** PUBLICATIONS **17** CITATIONS
SEE PROFILE


Teodorico Alves Sobrinho
Universidade Federal de Mato Grosso do Sul
**85** PUBLICATIONS **327** CITATIONS
SEE PROFILE

# ESTIMATION ON TIME OF CONCENTRATION OF OVERLAND FLOW IN WATERSHEDS: A REVIEW

**Isabel Kaufmann de ALMEIDA[1], Aleska Kaufmann ALMEIDA[1] , Jamil Alexandre Ayach ANACHE[2], Jorge Luiz STEFFEN[1], Teodorico ALVES SOBRINHO[1]**

**(1)** Universidade Federal de Mato Grosso do Sul, Faculdade de Engenharias, Arquitetura e Urbanismo e Geografia. Cidade Universitária, CEP 79070-900. Campo Grande, MS. Endereços eletrônicos: isabel.almeida@ufms.br; aleskaufmann@hotmail.com; jorgeluizsteffen@gmail.com; teodorico.alves@ufms.br.
**(2)** Universidade de São Paulo, Escola de Engenharia de São Carlos, Departamento de Hidráulica e Saneamento. Avenida Trabalhador Sancarlense, 400, Centro CEP 13566-590. São Carlos, SP. Endereço eletrônico: jamil.anache@usp.br.

**ABSTRACT -** The time of concentration is a fundamental parameter in many hydrological models. Nowadays there is no universally accepted definition for such parameter. However, many definitions and estimation procedures can be found in the technical literature. After an extensive bibliographic review, the current study brings up the variability of empiric methodologies used in its estimations. Thirty empiric methodologies were listed and estimations of time of concentration were performed by applying such methodologies using data from a rural watershed. The hierarchical cluster analysis (Cluster) was applied in order to assess the similarity degree among the selected methodologies. Among all methodologies, Pasini's and Ventura's are the ones that present higher similarity to each other, whereas Pasini and Arizona DOT show stronger dissimilarities to each other.
**Keywords:** Hydrographic survey, Basins, Outflow, Peak flow.

**RESUMO -** O tempo de concentração é parâmetro fundamental em diversos modelos hidrológicos. Atualmente não há definição universalmente aceita para esse parâmetro. No entanto, várias definições podem ser encontradas na literatura técnica, juntamente com procedimentos de estimativa relacionados. Após extensa revisão bibliográfica, este estudo traz à tona a variabilidade das metodologias empíricas utilizadas na sua estimativa. Foram relacionadas 30 metodologias empíricas e realizadas estimativas do tempo de concentração através da aplicação dessas metodologias aos dados de uma bacia hidrográfica rural. Aplicou-se a análise hierárquica de agrupamento (Cluster) a fim de examinar o grau de similaridade entre as metodologias selecionadas. Os resultados obtidos atestam que, dentre as metodologias analisadas, Pasini e Ventura são as que apresentam maior similaridade, enquanto que Pasini e Arizona DOT são as que demonstram maior dissimilaridade.
**Palavras-chave:** Levantamento hidrográfico, bacia, vazão de jusante, vazão de pico.

## INTRODUCTION

The time of concentration of overland flow is important to the hydrological analysis of watersheds, once it is substantial for estimations of maximum discharge. Being aware of the basin's behavior regarding time of concentration helps preventing and minimizing effects of natural disasters and punctual pollution of water resources. Among all response time parameters of the watershed, time of concentration is the most used one (McCuen et al., 1984; Wong 2009). According to Pavlovic & Moglen (2008), such parameter reflects how fast the watershed responds to rainfall events. Fang et al. (2008) call the attention to the importance of precision in estimations on time of concentration because, if the values for time of concentration are underestimated, they will lead to overestimated values for results related to peak discharge and vice versa.

There are many definitions to time of concentration as well as for related estimation processes. Eagleson (1970) defines it as the necessary time, used by the overland flow, to reach balance. McCuen et al. (1984) state that it is the necessary time taken by a water drop to superficially move itself from the most distant spot (within a hydraulic path) in the basin up to the outlet point. According to Chow et al. (1988), the time of concentration is the time spent by a single rain drop to move itself from the most distant spot in the basin until its outlet point. Eagleson (1970) defines it as the time spent by the overland flow to reach balance. McCuen et al. (1984) state that it is the necessary time spent by a single water drop to superficially move itself from the most distant spot in the basin (in hydraulic path) up to the outlet point. Wong (2005) considers it the elapsed time since the beginning of the rainfall event until the very moment when the equilibrium flow reaches 95%.

Many researchers (Kirpich, 1940; Dooge, 1956; Chow, 1962) have developed empiric equations using experimental and analytic methods in order to estimate the time of concentration. Each equation resulted from studies performed in different fields. They were adjusted according to local physical and hydrologic features. However, such equations are useful tools to estimate time of concentration within watersheds. They are usually used in experiments that involve parameter settings (Kang et al., 2008; Upegui & Gutiérrez, 2011; Liang & Melching, 2012). Sharifi & Hosseini (2011) suggested a method to identify the most effective equation to set time of concentration. Such method was applied to 72 watersheds and sub-watersheds. Fang et al. (2008) found many differences among time of concentration that were estimated by means of different formulas – using parameters of watersheds. Mata-Lima et al. (2007) have subdivided 20 methods of time of concentration’s calculation into two different categories: strictly empirical and semi-empirical. Silveira (2005) assessed the performance of 23 formulas for rural and urban basins as well as showed that the performance of such formulas is better to rural basins than it is to the urban ones.

According to such context, the current review was done in order to relate and characterize the use of different methodologies to estimate the time of concentration in watersheds. Thirty empiric equations were selected and estimations were performed by applying different equations that used data from a basin used as case study. The hierarchical cluster analysis (Cluster) was used to examine the similarity degrees among the selected methodologies.

## MATERIALS AND METHODS

Thirty empiric methodologies used to set time of concentrations of watersheds were selected after a detailed review of the literature. Throughout the selection of methodologies, those that use rainfall intensity were prioritized as well as the physical parameters of the watershed, because they are the most adequate to non-urban basins.

### Study area

Estimations of time of concentration were done by applying the selected methodologies using data from Córrego Guariroba's stream catchment located between 20° 28’ and 20° 43’ South latitude and 54° 29’ and 54° 11’ West longitude, in an area of 362 Km² (Figure 1). According to Köppen’s climatic classification, the climate in the region is Aw. It is defined as a warm and humid climate. The annual rainfall average varies between 1000 and 1700mm – rainfall season in summer, drought in winter and mean temperature in the coldest month is above 18°C.

Physical features, elevation data and the slope of the reference basin were based on topographic maps 1:100.000 (DSG, 1979). Such data were geo-referenced by Mercator’s (UTM, timezone 21, SAD 69) transverse projection within GIS environ. The hydrographic network was digitalized in GIS and it was ordered as per Strahler’s methodology (1964). Important information regarding the use and occupation of soil - that are used to estimate parameters and coefficients fixed in the equations, were obtained from the automatic supervised image classification of the Landsat 5 satellite (path/row 224/074) since June, 27th 2011 (I.N.P.E., 2013). They led to the mapping of use and occupation of the soil (Figure 2) that was categorized according to CORINE subtitle (Table 1). Field inspections were done in order to complete the collected information.

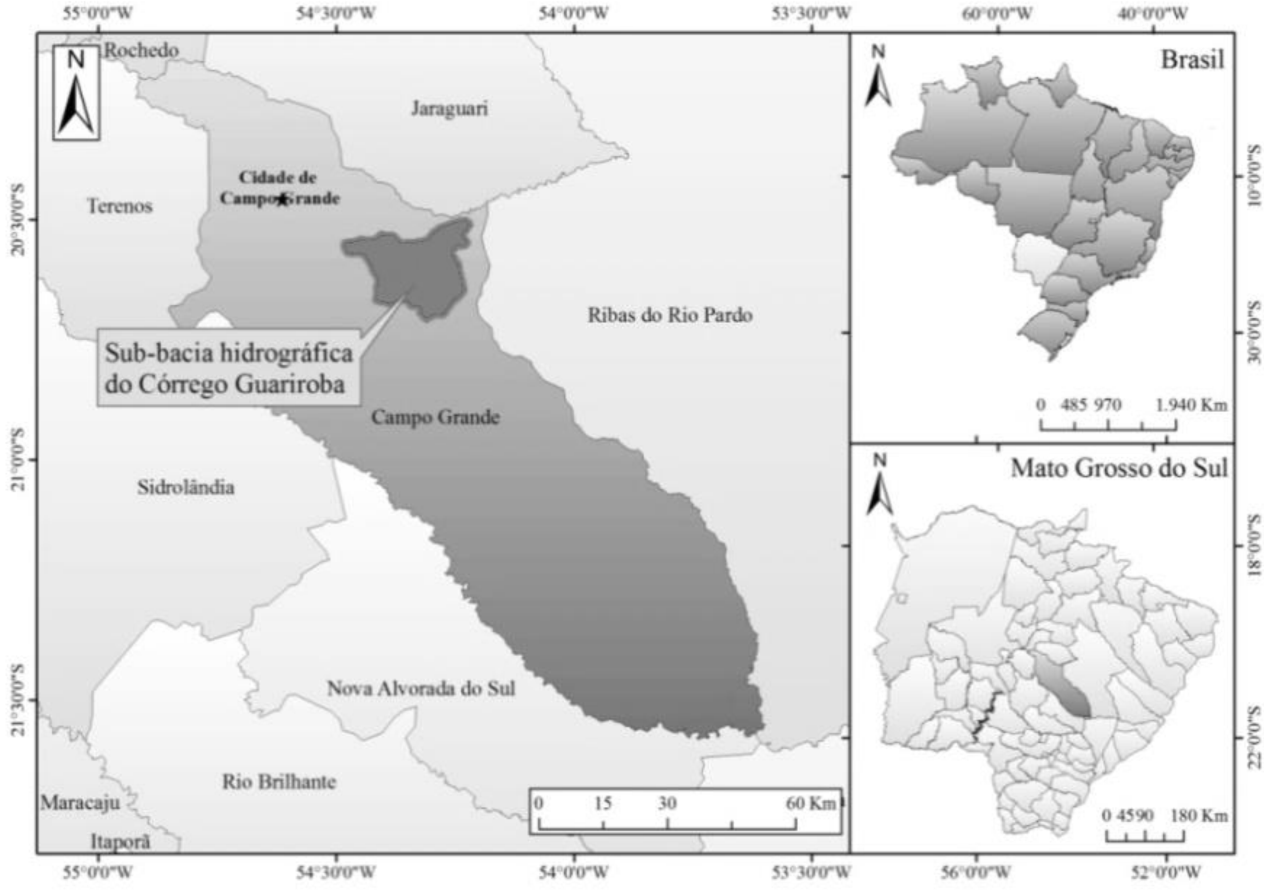

**Figure 1.** Location of the studied area.

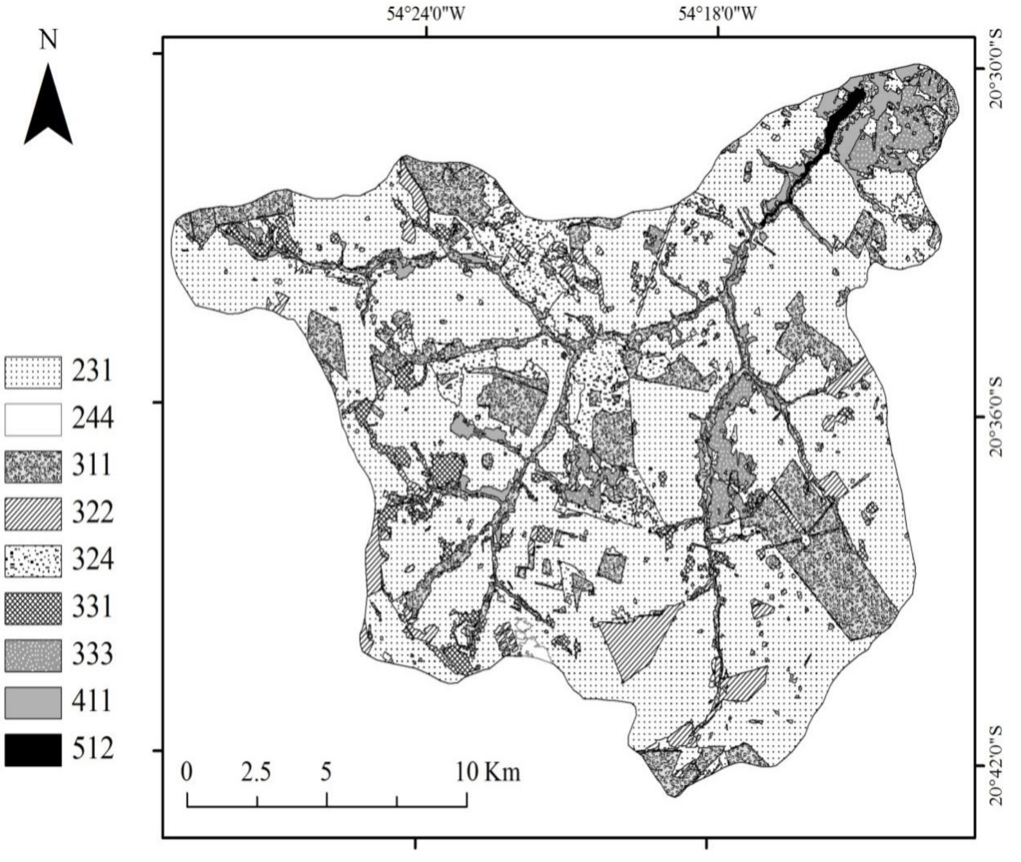

**Figure 2.** Map of use and occupation of the soil.

**Table 1.** CORINE land cover legend.

| | |
|---|---|
| Non-irrigated arable land | 211 |
| Pastures | 231 |
| Agro-forestry areas | 244 |
| Broad-leaved forrest | 311 |
| Moors and heathland | 322 |
| Transitional woodland-shrub | 324 |
| Beaches, dunes, sands | 331 |
| Sparsely vegetated areas | 333 |
| Inland marshes | 411 |
| Water bodies | 512 |

### Hierarchic cluster analysis (Cluster)

The hierarchic cluster analysis (Cluster) is an exploratory analysis technique which enables categorizing a set of observations into two or more groups that hold common features. It is based on combinations of variable intervals (Murali Krishna et al., 2008). By applying such analysis, the elements of the sample are organized into discrete groups according to certain criteria and goals. It means that, it is analyzed in a way that similarities inside the group are maximized and similarities among groups are minimized. This technique is highly used in many research fields such as Environmental Engineering (Hatvani et al., 2011), geomorphology (Melchiorre et al., 2008) and studies on water resources ( De Oliveira et al., 2010; Yoo et al., 2011; Li et al., 2012).

The cluster analysis enables identifying groups of variables relatively homogenous by dendograms based on the selected features. Data standardization is essential to the cluster analysis because parameters with higher variations tend to have stronger influence over those with lower variations, when Euclidian distance calculations are applied (Yidana et al., 2010). The Euclidian's distance methodology was used by the method of Ward. Such method is based on the criterion of minimum squares of linear models. It aims to define groups in a way that the sum of the squares in the groups is minimized (Borcard et al., 2011). According to Yoo et al. (2011), the method of Ward uses the variance approach in order to assess the distances among groups. As per Seidel et al. (2008), the Euclidean distance is the most frequent measurement of distance in use, when all variables are quantitative. Such distance is used in order to calculate specific measurements as well as the simple Eucledian distance and the quadratic and the absolute Eucledian distance is the sum of the squares of the differences, without the calculation of the square root, equation (1):

$$dE = \sum^{p}_{j=1} (X_{ij} – X_{Ij})^2 \qquad (1)$$

dE is the Eucledian distance; Xij is the j-th feature of the i-th individual; XIj is the j-th feature of the I-th individual. The closer the Eucledian distance is to zero, more similar the compared objects will be to each other.

## RESULTS AND DISCUSSION

Both the list of methodologies selected for the current study and the respective comments are presented in Table 2.

**Table 2.** List of methodologies of time of concentration estimations.

| Name | Equation | Comments | References |
|---|---|---|---|
| Kerby-Hathaway | $T_c = 0,6061 N^{0,47} L^{0,47} S^{-0,234}$ | Analysis of overland flow in experimental surfaces (L < 0,37 km) | Kerby (1959); McCuen et al. (1984). |

| Name | Equation | Comments | References |
|---|---|---|---|
| Kinematic wave | $T_c = 7{,}35n^{0{,}6}i^{-0{,}4}L^{0{,}6}S^{-0{,}3}$ | Analysis of overland flow in experimental surfaces (L <0,03 km) | Kibler (1982); Sharifi & Hosseini, (2011). |
| FAA | $T_c = 0{,}3788(1{,}1 - C)L^{0{,}5}S^{-0{,}333}$ | Data of aeroports' drainage | Chow et al. (1988); Silveira (2005). |
| Kirpich | $T_c = 0{,}0663L^{0{,}77}S^{-0{,}385}$ | Data of rural basins (0,004 - 0,453km$^2$) and (0,03<S<0,1) | Kirpich (1940); Fang et al. (2008). |
| SCS Lag | $T_c = 0{,}057\left(\frac{1000}{CN} - 9\right)^{0{,}7} L^{0{,}8}S^{-0{,}5}$ | Data of 24 rural basins in the USA (A <8 km$^2$) | Folmar et al. (2007) |
| Simas-Hawkins | $T_c = 0{,}322A^{0{,}594}L^{-0{,}594}S^{-0{,}150}S_{SCS}^{0{,}313}$<br>$S_{SCS} = \frac{25400}{CN} - 254$ | Data of 168 basins in the USA (0,001 - 14 km$^2$) | Simas–Hawkins (2002); Fang et al.(2008). |
| Ven te Chow | $T_c = 0{,}\,1602\ L^{0{,}64}S^{-0{,}32}$ | Data of 20 rural basins in the USA (0,01 – 18,5 km$^2$) and ( 0,0051<S<0,09) | Chow (1962); Silveira (2005). |
| Dooge | $T_c = 0{,}365A^{0{,}41}S^{-0{,}17}$ | Data of 10 rural basinsin Irland (145 - 948 km$^2$) | Dooge (1956); Silveira (2005). |
| Johnstone | $T_c = 0{,}4623L^{0{,}5}S^{-0{,}25}$ | Data of 19 rural basins in the USA (64,8 - 4206,1 km$^2$) | Johnstone & Cross (1949); Silveira (2005). |
| Corps Engineers | $T_c = 0{,}191L^{0{,}76}S^{-0{,}19}$ | Data of 25 rural basins in the USA (A≤12.000 km$^2$) | Linsley (1977); Silveira (2005). |
| Giandotti | $T_c = \frac{4\sqrt{A} + \frac{3}{2}L}{0{,}8\sqrt{H_m}}$ | Data of basins in central and northern Italy (170 - 70.000 km$^2$) | Giandotti (1940); Preti et al. (2011); Radice et al. (2012). |
| Pasini | $T_c = 0{,}108A^{0{,}333}L^{0{,}333}S^{-0{,}5}$ | Data of rural basins in Italy | Pasini (1914); Greppi (2005). |
| Ventura | $T_c = 4A^{0{,}5}L^{0{,}5}H^{-0{,}5}$ | Data of rural basins in Italy | Mata-Lima et al.(2007). |
| Picking | $T_c = 0{,}0883L^{0{,}667}S^{-0{,}333}$ | Data of rural basins | Mata-Lima et al.(2007); Silveira (2005). |
| DNOS | $T_c = 0{,}419k^{-1}A^{0{,}3}L^{0{,}2}S^{-0{,}4}$ | Data of 6 rural basins in the USA (A < 0,45 km$^2$) and (0,03<S<0,1) | Silveira (2005). |

| Name | Equation | Comments | References |
|---|---|---|---|
| George Ribeiro | $T_c = 0,267(1,05 - 0,2p)^{-1} L S^{-0,04}$ | Data of 7 rural basins in the USA and a rural basin in India (A < 19000km$^2$) and (0,03<S<0,1) | Ribeiro (1961). |
| McCuen et al. | $T_c = 2,2535 i^{-0,7164} L^{0,5552} S^{-0,2070}$ | Starting from data of 48 urbanbasins in the USA ((0,4 -16 km$^2$) and (0,0007<S<0,03) | McCuen et al. (1984); Fang et al. (2008). |
| Carter | $T_c = 0,0977 L^{0,6} S^{-0,3}$ | Data of an urban basin in the USA (A < 20,72 km$^2$ ) and (S < 0,005) | Carter (1961); Sharifi & Hosseini (2011). |
| Temez | $T_c = 0,3 \left(\frac{L}{S^{0,25}}\right)^{0,76}$ | Data of natural basins in Spain | Temez (1978); Mata-Lima et al. (2007). |
| Pickering | $T_c = \left(\frac{0,871\ L^3}{H}\right)^{0,385}$ | Equivalent to Kirpich's | Mata-Lima et al. (2007). |
| California Curvets Practice (CHPW) | $T_c = 0,95 \left(\frac{L^3}{H}\right)^{0,385}$ | Data of small mountain basins in the USA | Chow et al. (1988); Sharifi & Hosseini (2011). |
| Bransby Willians | $T_c = 0,605 \frac{L}{(100S)^{0,2} A^{0,1}}$ | Specially recommended to rural basins | MOTH (1998); ASDOT (1995). |
| Epsey | $T_c = 6,89 \left(\frac{L}{\sqrt{S}}\right)^{0,36}$ | Data of 11 rural basins in the USA | Hotchkiss & McCallum (1995); Mata-Lima etal. (2007). |
| Arizona DOT | $T_c = 0,0097956 A^{0,1} (1000 [\![L)]\!]^{0,25} L_{ca}^{0,25} S^{-0,2}$ | Data of agricultural basins | A.D.O.T., (1993); Sharifi & Hosseini (2011). |
| ASCE | $T_c = \frac{7,2983\ L^{0,6} n^{0,6}}{i^{0,4} S^{0,3}}$ | Analysis on the kinematic wave (L<0,09 km) | Morgali & Linsley (1965); Kang et al. (2008). |
| Woolhiser& Liggett's | $T_c = 7,3015 \left(\frac{nL}{S^{0,5}}\right)^{0,6} i^{-0,4}$ | Based on the theory of kinematic wave | Woolhiser &Liggett's (1967); Wong (2005). |
| Yen & Chow's | $T_c = 1,2 \left(\frac{nL}{S^{0,5}}\right)^{0,6}$ | Based on the theory on the kinematic wave | Yen & Chow's (1983); Wong |

| Name | Equation | Comments | References |
|---|---|---|---|
| | | | (2005). |
| Williams | $T_c = \frac{0{,}272\, LA^{0{,}4}}{DS^{0{,}2}}$ | Data of basins in India (A <129,5km$^2$) | Williams (1922); Fang et al. (2008). |
| Haktanir&Sezen | $T_c = 0{,}7473\, L^{0{,}841}$ | Data of 10 basins in Turkey (11-9867km²) | Haktanir & Sezen (1990); Fang et al. (2008). |
| Papadakis& Kazan | $T_c = \frac{2{,}1539\, n^{0{,}52} L^{0{,}5}}{i^{0{,}38} S^{0{,}31}}$ | Data of 84 rural basins in the USA (A <5 km$^2$) | Loukas & Quick (1996); USDA.NRCS (2010). |

Note: Tc (h) = time of concentration; A (Km²) = area of the watershed; C (adm) = overland flow coefficient of the rational method; CN (adm) = Curve-number parameter of the SCS method; D (Km) = equivalent diameter of the watershed; H (m) = quota difference between the ends of the main water line; Hm (m) = mean altitude in the basin ( it is the mean elevation starting from the mouth); i (mm/h) = rainfall intensity; K (adm) = coefficient of the type of surface; L (Km) = length of the main water line; Lca (m) = mean length starting from the concentration spot along the L up to the spot where L is perpendicular to the centroid (barycenter) of the basin; N (adm) = retardance coefficient; n ($m^{-1/3}$.s) = Manning's roughness coefficient; p (adm) = relation between the vegetation cover and the total area of the basin; S (m/m) = mean steepness (ratio between the mean fall and the L length of the course); $S_{scs}$ (mm) = maximum capacity of retention; Tc (h) = time of concentration.

The expression of Kerby-hatheway can be applied to basins that present different features (McCuen et al., 1984). According to Sharifi & Hosseini, (2011) the equation of Kinematic wave is based on the theory of kinematic wave, considering flow surface as a considerably large canal and taking under account the hypotheses of turbulent flow and constant rainfall intensity. Such equation is adequate to basins in which the surface flow prevails. The authors state that FAA is indicated to watersheds that present significant sealing rates. Kirpich (1940) recommended applying his adjustment curves only to rural basins that present area between 0.0040 and 0.8094 km$^2$. SCS Lag suits small rural basins in which the superficial flow is prevalent. According to Nunes & Fiori (2008), in regards to the method of VenTe Chow, the maximum discharges are proportional to the effective rainfall. As per such method, effective rainfall is responsible for flood flows, mainly in urbanized basins.

Due to Dooge's method, the parameters reflect the behavior of medium sized basins as well as the prevailing flows in the canals. Giandotti's equation is commonly used in Europe, mainly in Italy. Thus, diverse authors have been getting coherent results by applying the methodology to Italian basins. López et al. (2010) and Radice et al. (2012) highlight that its use is mainly appropriate to mountainous basins. Greppi (2005) have suggested that Pasini's equation must be applied to basins presenting smooth steepness. Luino et al. (2009) have used such equation in flood studies and state that it was published in Pasini's (1914) work. Ventura is indicated to rural basins and, according to Mata-Lima et al. (2007), Temez's methodology suits natural basins presenting area as large as 3000 Km². The Bransby Willians method is mainly recommended to natural basins.

Arizona DOT is a modified form of FAA. It was developed from data from agricultural watersheds. In regards to ASCE, despite the fact that it is recommended only to L< 0.09 km basins, Kang et al. (2008) proved its good performance in studies on big basins. Yen & Chow's (1983) had proposed simplifying the ASCE. Williams (1922) developed the equation after performing a study on flood flow in India. Haktanir & Sezen (1990) developed their methodology using a regression analysis using data from basins located in Turkey.

### Watershed physiographic features

The summary of the physiographic features and parameters used to estimate the time of concentration in the studied basin is shown in Table 3.

**Table 3.** Physiographic features and parameters of Córrego Guariroba Basin.

| Feature | Value | Feature | Value | Feature | Value |
|---|---|---|---|---|---|
| A (km²) | 361.940 | Hm (m) | 84.453 | N (adm) | 0.800 |
| C (adm) | 0.010 | i (mm/h) | 35.000 | n ($m^{-1/3}$. s) | 0.037 |
| CN (adm) | 67.000 | k (adm) | 2.500 | p (adm) | 0.245 |
| D (km) | 21.467 | L (km) | 32.150 | S (m/m) | 0.003 |
| H(m) | 100.450 | Lca (m) | 16085.200 | $S_{scs}$(mm) | 125.105 |

Results obtained with the application of the selected equations are presented in Table 4. It was observed a relative difference of 94,98 % among the obtained results.

**Table 4.** Tc values obtained with the application of the selected equations.

| Method | Tc(h) | Method | Tc(h) | Method | Tc(h) |
|---|---|---|---|---|---|
| Kerby-Hathaway | 10.560 | Giandotti | 16.982 | CaliforniaCurvets Practice | 8.867 |
| Kinematic wave | 11.105 | Pasini | 43.657 | Bransby Willians | 13.619 |
| FAA | 15.986 | Ventura | 43.052 | Epsey | 67.886 |
| Kirpich | 8.844 | Picking | 6.103 | Arizona DOT | 8.441 |
| SCS Lag | 56.916 | DNOS | 19.746 | ASCE | 11.027 |
| Simas-Hawkins | 14.611 | George Ribeiro | 10.801 | Woolhiser & Liggett’s | 11.032 |
| Ven te Chow | 9.354 | McCuen et al. | 4.001 | Yen & Chow’s | 7.517 |
| Dooge | 10.896 | Carter | 4.424 | Williams | 13.631 |
| Johnstone | 11.088 | Temez | 12.549 | Haktanir & Sezen | 13.837 |
| Corps Engineers | 7.990 | Pickering | 8.851 | Papadakis & Kazan | 3.406 |

Ryberg (2006), states that the dendogram clearly evidences all the different behaviors. It also interprets the groups descriptions by using a hierarchic graphic format. Many studies have been done in order to set the proper number of groups (Aaker et al., 2008). A bigger or smaller number of groups can be defined by moving the position of the cutting point upwards or downwards (Güler et al., 2002). In the dendogram - regarding the analyzed methodologies - both the vertical scale and the horizontal axis indicate the level of similarity. The methodologies are listed following the order in which they are grouped (Figure 3).

Groups were analyzed within different levels based on the Euclidean distance. By the time two groups were set, Pasini, Ventura, SCS Lag and Epsey have integrated the same group, which is featured by low Euclidean distance and different behavior. All other methodologies were gathered in another group – longer Euclidean distance. The performance of Ventura, SCS Lag and Epsey corroborates the similarity among the recommendations listed in the literature, once they are equally indicated to small rural basins. Based on a more detailed analysis, subgroups that vary according to the significance of the Euclidean distance were also categorized in the group. Pasini and Ventura that were originated in Italian rural basins as well as SCS Lag and Epsey based on American rural basins, group themselves in pairs. Pasini and Ventura, that present shorter Euclidean distance, show higher similarity.

The group formed by Pasini, Ventura, SCS Lag and Epsey was kept on level 6. Temes, which is appropriate to natural basins, was linked to Simas-Hawkins, Haktanir & Sezen, Bransby Willians and Williams. DNOS was kept isolated and the FAA was grouped with Giandotti. Picking and Papadakis & Kazan, both originated from studies on rural basins, were linked McCuen et al. and Carter, that were developed from data of urban basins. The other methodologies, comprised by: ASCE, Woolhiser & Liggett’s, Kinematic wave, Johnstone, Dooge, Kerby-Hathaway, George Ribeiro, California Curvets Practice, Kirpich, Pickering, Yen and Chow’s, Corps Engineers and Arizona DOT were the last, on this level, to be gathered.

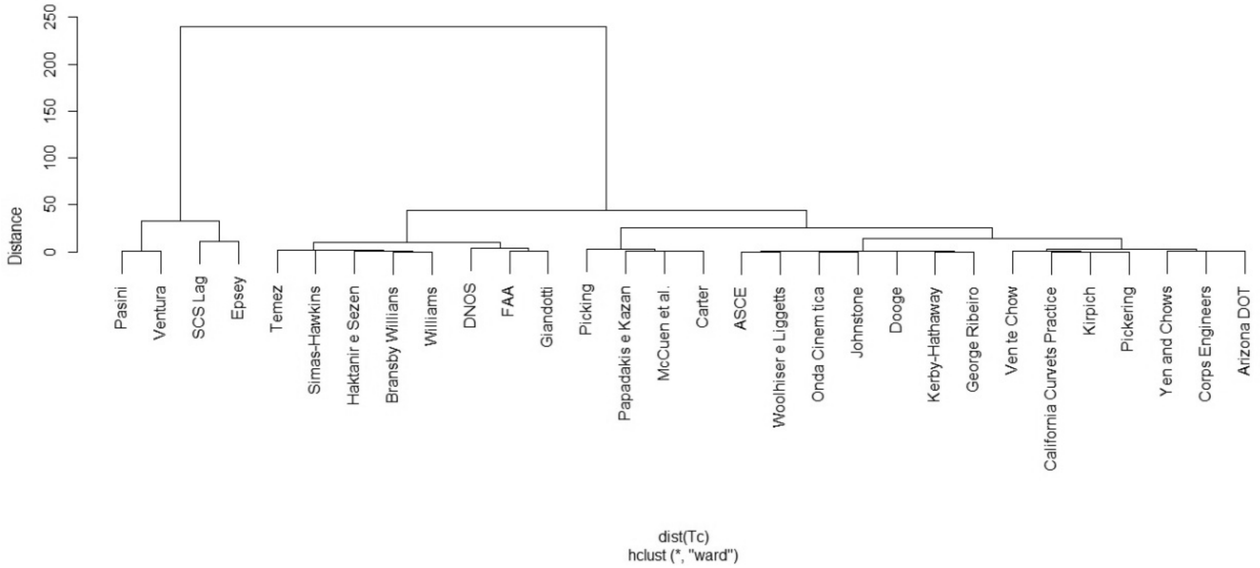

**Figure 3.** Dendogram resulting from the methodologies' grouping process.

In group level 15, the group formed by Pasini, Ventura, SCS Lag and Epsey was kept. Simas-Hawkins, Haktanir & Sezen, Bransby Willians and Williams were in the same group. Such methodologies were developed based on data from basins showing different physical features and located in different continents. They presented common parameters for the length of the main water line. FAA, which holds basins presenting significant sealing rates, was linked to Giandotti, which is properly used in mountainous basins. Although they come from distinct origins, it is possible verifying the influence of steepness in both methodologies. The group formed by McCuen et al. and Carter leads to strangeness, once both were originated in studies on urban basins that present smooth steepness and are similarly dependent on the length of the main water line as well as on the mean steepness, although McCuen et al. demand intense rainfall, fact that does not happen to Carter. ASCE and Woolhiser & Liggett's present similarities since their origin till the composition of the same parameters in their formulation.

However, the proximity between the kinematic wave and Johnstone was strange, once the second comes from studies on rural basins in different areas and the first comes from experiments done in plots, despite the fact that the kinematic wave is considered adequate to very small basins, what does not happen to Johnstone. The same thing happens to the group formed by Dooge, Kerby-Hathaway and George Ribeiro. Dooge comes from data of Irish rural basins that present varied dimensions as well as better performance in small areas of drainage. Kerby-Hathaway results from the superficial flow analysis performed in plots and it can be applied to basins that present various features. George Ribeiro results from studies performed in basins from different continents. It presents good results within urban basins. California Curvets Practice, Kirpich and Pickering present similar influence from the following parameters: length of the main water line and the mean steepness in their formulations. CorpsEngineers, once adjusted to data from rural basins, was linked to Arizona DOT, which was originated in agricultural basins. The methodologies Temez, DNOS, Picking, Papadakis & Kazan, Ven te Chow and Yen & Chow's were kept away from the groupings.

It is possible observing that the groups formed in each grouping level are distinct from each other. It means that there is homogeneity inside each group and heterogeneity among groups. In other words, methodologies were grouped because they presented common features. We have also observed that the groupings: Pasini and Ventura, Corps Engineers and Arizona DOT are the ones that present stronger similarity in regards to analyses performed amidst groups. The methodologies that have presented more similar behaviors were Pasini and Ventura.

## CONCLUSION

There is a behavioral variability among the studied methodologies and the approaches available to the estimation of time of concentration, which can generate numeric previsions that are different from each other (it can reach up a relative difference of 94,98 %).

Regular and intensive hydrological monitoring is necessary to select the proper estimation methodology to measure the time of concentration in river basins.

Among the analyzed methodologies, Pasini and Ventura are the ones that present higher similarity. However, in regards to Corps-Engineers and Arizona DOT, Pasini and Ventura show higher dissimilarity when they are applied using data from rural river basins in tropical climate regions.

## BIBLIOGRAPHY

1. AAKER, D. A., KUMAR, V., AND DAY, G. Marketing research, John Wiley & Sons, 2008.
2. A.D.O.T. (Arizona Department of Transportation). Highway drainage design manual hydrology, Phoenix, 1993.
3. ASDOT. Alaska highway drainage manual. Alaska (USA): Alaska State Department of Transportation. Chapter 7: Hydrology. 1995.
4. BORCARD, D., GILLET, F., LEGENDRE, P. Numerical ecology with R. Springer, 306 p., 2011.
5. CARTER, R. W. Magnitude and frequency of floods in suburban areas. U.S. Geological Survey Professional Paper, v. 424-B, p. 9-11, 1961.
6. CHOW, V.T. Hydrologic determination of waterway areas for the design of drainage structures in small drainage basins. Engineering Experiment Station Bulletin n.462. Urbana, Ill.:University of Illinois College of Engineering, 104 p., 1962.
7. CHOW, V.T., MAIDMENT, D.R., MAYS, L.W. Applied hydrology. New York. McGraw-Hill. 570 p., 1988.
8. DE OLIVEIRA, D.P., GARRETT, J.H. JR, SOIBELMAN, L. Detecting plant spatial patterns, using multidimensional scaling and cluster analysis, in rural landscapes in Central Iberian Peninsula. Landsc Urban Planning, v. 95, n. 3, p. 138–150, 2010.
9. DIRETORIA DE SERVIÇO GEOGRÁFICO DO EXÉRCITO (DSG). Carta Lagoa Rica. Folha SF-21-X-B-VI (MI – 2588). Escala 1:100.000. DSG, 1979.
10. DOOGE, J.C.I. Synthetic unit hydrographs based on triangular inflow. Iowa State University, 1656. 103 p. Thesis.
11. EAGLESON, P. S. Dynamic hydrology. New York. McGraw-Hill, 462 p., 1970.
12. FANG, X., THOMPSON, D. B., CLEVELAND, T. G., PRADHAN, P., AND MALLA, R. Time of concentration estimated using watershed parameters determined by automated and manual methods. Journal of Irrigation and Drainage Engineering, v. 134, n. 2, p. 202–211, 2008.
13. FOLMAR, N.D.; MILLER, A.C.; WOODWARD, D.E. History and development of the NRCS lag time equation. Journal of the American Water Resources Association, v.43, n.3, p. 829-838, 2007.
14. GIANDOTTI, M. Previsione empirica delle piene in base alle precipitazioni meteoriche, alle caratteristiche fisiche e morfologiche dei bacini; Applicazione del metodo ad alcuni bacini dell’Appennino Ligure. Memorie e Studi Idrografici, v. 10, p. 5-13, 1940.
15. GREPPI, M. Idrologia. 4. ed. Milano: Ed. UlricoHoepli, 371p., 2005.
16. GÜLER, C., THYNE, G., MCCRAY, J.E., TURNER, K.A. Evaluation and graphical and multivariate statistical methods for classification of water chemistry data. Hydrogeology Journal, v. 10, p. 455-474, 2002.
17. HAKTANIR, T., SEZEN, N. Suitability of two-parameter gamma and three-parameter beta distributions as synthetic unit hydrographs in Anatolia. Hydrological Sciences Journal, v. 35, n. 2, p. 167–184, 1990.
18. HATVANI, G. I.; KOVÁCS, J.; KOVÁCS, I. S.; JAKUSCH, P.; KORPONAI, J. Analysis of long-term water quality changes in the Kis-Balaton Water Protection System with time series, cluster analysis and Wilk’s lambda distribution. Ecological Engineering, v. 37, p. 629-635, 2011.
19. HOTCHKISS, R.H., MCCALLUM, B.E. Peak discharge for small agricultural watersheds, Journal of HydraulicEngineering, v. 121, n. 1, p.36-47, 1995.
20. I.N.P.E. Imagem LANDSAT 5 ThematicMapper (TM), canais 1, 2 ,3 ,4, 5, 6, 7, órbita 224, ponto 74, de 27 junho 2011. São José dos Campos, SP, 2013.
21. JOHNSTONE, D. & CROSS, W.P. Elements of applied hydrology. New York: The Ronald Press Company, 276 p., 1949.
22. KANG, J.H.; KAYHANIAN, M.;STENSTROM, M.K. Predicting the existence of stormwater first flush from the time of concentration. Water Research, v.42, p. 220-228, 2008.
23. KERBY, W.S. Time of concentration for overland flow. Engineers notebook. v.174, p. 60, 1959.
24. KIRPICH, T.P. Time of Concentration of Small Agricultural Watersheds. Journal of Civil Engineering, v.10, n.6, p. 362, 1940.
25. KIBLER, D. F. Desk-top methods for urban stormwater calculation. Urban stormwater hydrology, D. F. Kibler, ed., American Geophysical Union, Water Resources Monograph, v. 7, p. 87–135, 1982.
26. LIANG, J. & MELCHING, C.S. Comparison of Computed and Experimentally Assessed Times of Concentration for a V-Shaped Laboratory Watershed. Journal of Hydrologic Engineering, v. 17, n. 12, p. 1389 - 1396, 2012.
27. LI, J., WANG, Y., XIE, X., SU, C. Hierarchical cluster analysis of arsenic and fluoride enrichments in groundwater from the Datong basin, Northern China. Journal of Geochemical Exploration v.118, p. 77-89, 2012.
28. LINSLEY, R. K., KOHLER, M. A., PAULHUS, J. L., SERRA, M. F., & APARICIO, F. D. Hidrología para ingenieros. McGraw-Hill. 386 p., 1977.
29. LÓPEZ, Y.R.; LEÓN, N.M.; URRUTIA, L.G. Modelo lluviaescurrimiento para La cuenca Del rio Reno

Rainfall–runoff model for Reno´s river basin. Revista Ciencias Técicas Agropecuarias., v.19, n.2, p. 31- 37, 2010.

30. LOUKAS, A. & QUICK, M.C. Physically-based estimation of lag time for forested mountainous watersheds. Hydrological Sciences Journal, v.41, n.1, p.1-19, 1996.

31. LUINO, F.; CIRIO, C.G.; BIDDOCCU, M.; AGANGI, A.; GIULIETTO, W.; GODONE, F.; NIGRELLI, G. Application of a model to the evaluation of flood damage. Geoinformatica, v.13, n.3, p. 339-353, 2009.

32. MATA-LIMA, H.; VARGAS, H.; CARVALHO, J.; GONÇALVES, M.; CAETANO, H.;MARQUES, A.; RAMINHOS, C. Comportamento hidrológico de bacias hidrográficas:integração de métodos e aplicação a um estudo de caso. Revista Escola de Minas, v. 60, n. 3, 2007.

33. McCUEN, R.H.; WONG, S.L.; RAWLS, W.J. Estimating urban time of concentration. Journal of Hydraulic Engineering, v.110, n.7, p. 887-904, 1984.

34. MOTH. Hydraulics manual. Columbia: Ministry of Transportation and Highways (MOTH), Engineering Branch. Province of British, 1998.

35. MORGALI, J.R. & LINSLEY, R.K. Computer analysis of overland flow. Journal of the Hydraulics Division, ASCE 91 (HY3), p. 81–101, 1965.

36. MURALI KRISHNA P.S. M., MOSES, S. G., V.S.G.K. MURALI KRISHNA, Application cluster analysis, discriminate analysis and principal component analysis for water quality evaluation for the river Godavari at Rajahmundry region, International Journal of Applied Environmental Sciences, v. 2, n. 3, 195-209, 2008.

37. NUNES, F. G. & FIORI, A. P. A utilização do Método de Ven Te Chow–Soil Conservation Service (SCS) na estimativa da vazão máxima da bacia hidrográfica do Rio Atuba. Revista Geografar, v. 2, n. 2, 2008.

38. PASINI, F. Relazione sul progettodella bonifica renana, Bologna, Italy, 1914.

39. PAVLOVIC, S. B. & MOGLEN, G. E. Discretization issues in travel time calculation. Journal of Hydrologic Engineering, v. 13, n. 2, p. 71 -79, 2008.

40. PRETI, F.; FORZIERI, G.; CHIRICO, G. B. Forest cover influence on regional flood frequency assessment in Mediterranean catchments. Hydrology and Earth System Sciences, v.15, n.10, p. 3077-3090, 2011.

41. RADICE, A.; GIORGETTI, E.; BRAMBILLA, D.; LONGONI, L.; PAPINI, M. On Integrated Sediment Transport Modelling for Flash Events in Mountain Environments. ActaGeophysica, v.60, n.1, p. 191- 213, 2012.

42. RIBEIRO, G., 1961, Acerca do calculo da vasão de obras d'arte : tempo de concentração, Revista do Clube de Engenharia, n. 294, p. 16-19, 1961.

43. RYBERG, K.R. Cluster Analysis of Water-Quality Data for Lake Sakakawea, Audubon Lake, and McClusky Canal, Central North Dakota, 1990-2003, Prepared in cooperation with the Bureau of Reclamation, U.S. Department of the Interior Scientific Investigations Report 2006-5202, U.S. Geological Survey, Reston, Virginia, 47p., 2006.

44. SEIDEL, E.J.; MOREIRA JÚNIOR, F. de J.; ANSUJ, A. P.; NOAL, M. R. Comparação entre o método Ward e o método K-médias no agrupamento de produtores de leite. Ciência e Natureza, v.30, n.1, p.7- 15, 2008.

45. SHARIFI, S. & HOSSEINI, S. M. Methodology for Identifying the Best Equations for Estimating the Time of Concentration of Watersheds in a Particular Region. Journal of Irrigation and Drainage Engineering, v. 137, n. 11, p. 712-719, 2011.

46. SILVEIRA, A.L.L. Performance of time of concentration formulas in urban and rural basins. Revista Brasileira de Recursos Hídricos, v.10, p.5-23, 2005.

47. SIMAS, M. J. & HAWKINS, R. H. Lag time characteristics in small watersheds in the United States. 2nd Federal Interagency Hydrologic Modeling Conference, Las Vegas, 2002.

48. STRAHLER, A. N. Quantitative Geomorphology of Basin and Channel Networks: Handbook of Applied Hydrology. Mc graw Hill, New York, 1964.

49. TEMEZ, J.R. Calculo hidrometeorologico de caudales maximos em pequeñas cuencas naturales. Madrid: Ministério de Obras Publicas y Urbanismo (MOPU). Direccion General de Carreteras, n. 12, 1978.

50. UPEGUI, J. J.V. & GUTIÉRREZ, A.B. Estimación del tiempo de concentración y tiempo de rezago en la cuenca experimental urbana de la quebrada San Luis, Manizales. Dyna, v. 78, n. 165, p. 58-71, 2011.

51. USDA. NRCS, National Engineering Handbook. Part 630 Hydrology. Cap. 15: Time of Concentration, Washington, DC. 29 p., 2010.

52. WILLIAMS, G. B. Flood discharges and the dimensions of spillways in India. Engineering, v. 134, p. 321-322, 1922.

53. WONG, T. S. W. "Assessment of time of concentration formulas for overland flow. Journal of Irrigation and Drainage Engineering, v. 131, n. 4, 2005.

54. WONG, T. S. W. Evolution of Kinematic Wave Time of Concentration Formulas for Overland Flow. Journal of Hydrologic Engineering, v. 14, n. 7, 2009.

55. WOOLHISER, D.A. & LIGGETT, J.A. Unsteady, One-Dimensional Flow over a Plane the Rising Hydrograph. Water Resources Research, v.3, n.3, p. 753-771, 1967.

56. YIDANA, S.M., YAKUBO, B.B., AKABZAA, T.M. Analysis of groundwater quality using multivariate and spatial analyses in the Keta basin. Ghana. Journal of African Earth Sciences v. 58 n. 2, p. 220–234, 2010.

*57.* YEN, B. C., & CHOW, V. T. 1983. Local design storms, Vol III. Rep. H 38 No.FHWA-RD-82/065, U.S. Dept. of Transportation, Federal Highway Administration, Washington, D.C. 1983.

58. YOO, C., KU, H., KIM, K. Use of a Distance Measure for the Comparison of Unit Hydrographs: Application to the Stream Gauge Network Optimization. Journal of Hydrologic Engineering, v. 16, n. 11, p. 880-890, 2011.

*Manuscrito recebido em: 18 de Agosto de 2014*
*Revisado e Aceito em: 12 de Novembro de 2014*