Methodology for Identifying the Best Equations to Estimate the Time of Concentration of Tropical Watersheds in Puerto Rico

Tania Michelle Martínez Guzmán
Master of Engineering in Civil Engineering
Christian A. Villalta Calderón, PhD.
Civil and Environmental Engineering Department
Polytechnic University of Puerto Rico

Abstract *— The time of concentration (tc) is the time required for runoff to travel from the hydraulically most distant point to the outlet of a watershed. The lag time is the most sensitive parameter and is defined as the sixty percent of the tc. This research was focused in the evaluation of the use of time of concentration parameter in Puerto Rico and also if the parameter are used correctly for the conditions for which they were created in order to define a methodology for the best use of each available equation. The NRCS velocity method was used as the reference method for computing time of concentration value and compare the accuracy of the estimates from other time concentration methods. This research illustrated the high variability associated with the time of concentration values depending on the method employed. According to this research, the SCS Lag equation have the best performance for the selected seven watersheds analyzed.*

Key Terms *— Peak Discharge, Sensitive Parameter, Time of Concentration, Tropical Watershed.*

INTRODUCTION

For the planning, design and construction of drainage systems are necessarily accurate estimates of several parameters that includes the lag time, time of concentration, curve number and other parameters, all of them related to peak discharge computation. An erroneous result in hydrologic site calculations results in drainage systems being planned and built that are either undersized or oversized.

One of the most important parameters to estimate hydrological condition in a site is the time of concentration (tc). Tc depends on the rainfall and watershed characteristics [1] and it is used in the analysis for soil planning and water resources management. Tc is a site-specific parameter and a lot of methods have been developed around the world. In this research, an analysis of the most used methods in Puerto Rico and methodologies that applies to tropical watersheds will be presented and analyzed in order to have an accurate approximation when compute the peak discharge. Therefore, the purpose of this study is to select the best available methods for estimating the time of concentration in a tropical country. For this reason, seven watersheds located in Puerto Rico were evaluated applying different equations to estimate tc in order to define the best equation selection according to specific site conditions. For this purpose, a statistical analysis including parameters like mean deviation, mean difference, relative error percentage, mean square error, and comparison of mean were performed.

The aim of this study is the determination of the best method for estimating the tc in the analyzed tropical watersheds in Puerto Rico and next to draw conclusions on which is more advantageous; to decide if is better to use a formula that overestimate or underestimate the parameter value.

JUSTIFICATION

The time of concentration is the most sensitive parameter involved in the process to estimate peak discharges in a hydrologic design. Based in a sensibility analysis, (Torres, 2012) the time of concentration was the parameter most sensitive presenting the greatest [2] differences in a comparison between hydrological studies prepared using the common practice (watershed parameters calculated by hand) and the ones calculated using HEC-GeoHMS tools. In the common practice, lag time computation methodology is defined by the water resources engineer, who decides which formula will be used to calculate it. Actually is not available a clear methodology to choose the best time of concentration methods to calculate it, so the hydrology professional use their engineer judgment criteria. Also the accuracy of the estimated peak discharge is sensitive to the accuracy of the estimated time parameter because this parameter influences the results significantly. For this reason using an appropriate value for time of concentration is very important in a hydrologic and hydraulic study. The motivation to present this research is to create awareness among professionals in Puerto Rico of the importance of selecting the best method to estimate the time of concentration.

LITERATURE REVIEW

The foundation for projects involving site development, roadways, canalizations, bridge design, improvements of the water resources and other engineering projects is the combination of hydrologic studies and hydraulic analysis of the site properties. The Hydrologic Hydraulic (HH) study provides the analysis and recommendations to achieve a better management of the water resources. An important variable that is included in that study is the peak discharge that is the maximum [3] volume flow rate passing a particular location during a storm event. The peak discharge is a primary design variation for pipe systems, open channels, Culvers, dams, storm inlets and other hydraulic systems. It is also used for some hydrologic planning such as small detention facilities in urban areas. Peak discharge has units of volume/time (e.g. ft^3/Sec, m^3/Sec, acre-feet/hour).

The time of concentration (tc) is the time required for runoff to travel from the hydraulically most distant point of the watershed [4] to the outlet or design point as shown in figure 1. The travel time is the time it takes water to travel from one location to another in a watershed and is a component of time of concentration. The lag is the delay between the times runoff from a rainfall event over a watershed begins until runoff reaches its maximum peak. The lag time is an estimate of the average flow time for all locations on a watershed and is related to the time of concentration by (1)

$$t_L=0.6t_c \quad (1)$$

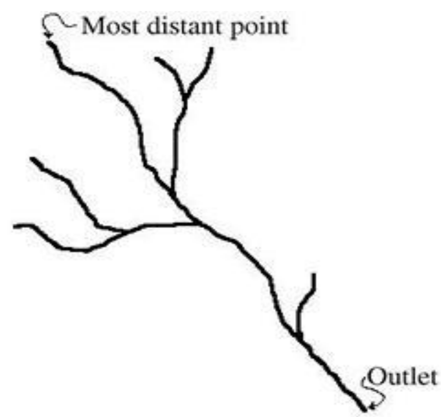

Figure 1
Time of Concentration Illustration

The time of concentration played a very important role in the size of the discharge. The factors affecting time of concentration are surface roughness, channel shape, flow patterns and the slope. The peak discharge is a function of the rainfall intensity which is based on the time of concentration. For this reason this parameter is a fundamental watershed parameter which is used to compute the peak discharge for a watershed rate and also flow patterns under given rainfall characteristics. Also, this parameter influences the shape and peak of the runoff hydrograph.

Sensitivity analysis is a method by which the effects of existing variations in models on their results can be investigated. Torres (2013) presents a sensitivity analysis used as a test for the comparison between hydrological studies prepared using the common practice and the GIS integration as a newer practice in the water resources industry in tropical regions. He found lag time is a very sensitive parameter producing more disturbances in the flow results when the parameter is reduced than when is increased and underestimating the time of concentration causes a further increment in the model's results.

Torres (2013) in his local sensibility analysis have proven the lag time was the parameter presenting the greatest difference between the original study and the ones calculated using HEC-GeoHMS tools. This difference influences the results significantly producing an inverse proportional relationship proportional to the HEC-HMS model results. The lag time showed considerable variations from the original studies values, in which the variation is directly dependent on the methodology and formula selected for its calculations. The parameter increment produces a reduction in the flow results and a flow increment when the parameter is reduced.

Finally, Torres (2013) concluded, although have been shown the parameter sensibility, often the engineers are confused when selecting a method for calculates time of concentration between the available formulas in the literature without knowing exactly the accuracy of each formula.

McCuen at al (1984) assumed that tc computed using the velocity method was the “true” value and he used that value as the basis for comparing other empirical formulas. Essentially, McCuen et al 1984 tries to assess the accuracy of some of these formulas. He estimates the time of concentration by the use of 11 empirical equations [5] used for estimating tc and find a wide variation in the results. Eleven equations for estimating tc are compared using data collected from 48 urban watersheds located in most regions of the country. The average tc computed by the velocity method for the 48 watersheds agrees very nearly with the mean time computed from rainfall and hydrography data. Also they evaluated 7 empirical equations of tc for 5 urban watersheds. They concluded that measuring tc through men waterway velocity presented by National Resources Conservation Services (NRCS) velocity method had the minimum error. They agreed the time of concentration is a critical term, and the common engineering practice doesn’t give adequate attention to it.

There are several methods for determining tc values, so it is important to consider the conditions for which the method was developed and how they compare to the drainage area being evaluated or the facility to be designed. Each method has some restrictions that limit its applicability. One of the most used methods in the world is the Natural Resources Conservation Service (NRCS) velocity method that is commonly used to estimate tc *for* hydrologic analysis and design. This method applies the physical concept that travel time is a function of runoff flow length [6] and flow velocity.

Sharity et al. (2011) proposed a methodology for identifying the best equation of tc for watersheds located in a specific geographic region. The methodology is applied to the 72 watersheds in Iran and tc [7] considered as “reference” is determined using the (NRCS) velocity method employed in the TR-55 model for each watershed because the NRCS velocity method relies on a solid hydraulic basis [8] for estimating flow velocity and also this method has been selected as most accurate method for calculating tc in urban watersheds and non-urban watersheds. The methodology primarily works on the basis of modifying available equations to minimize their bias for any particular region of interest. Then the author evaluate and select the best performing method uses a ranking-based selection strategy and he concluded that the California equation, Kirpich Equation and the Arizona DOT equation have the best performance for the selected watersheds in Iran.

Vahabzadeh et al. (2013) try to assess the accuracy of ten tc methods [9] for two watershed in Iran. The equations of estimating tc were evaluated using mean deviation, mean difference, relative error percentage, mean square error tests and comparison method of mean by Tukey method. Overall results demonstrated that, the Rational Hydrograph equation is the most appropriate equation and Bransly-Williams equation is not recommended because of very much difference with observed data.

Relation between the Lag Time and Peak Flow

In the common practice, lag time computation methodology is defined by the water resources engineer, who decides which formula will be used to calculate it. That available information and tools as well as professional criteria help the engineers to make the right decision. The errors in time of concentration estimation contribute to errors in estimation of design parameters. Bondelid et al (1982) indicated that as much as 75% of the total error in estimates of peak discharge [10] could result from errors at the time of concentration estimate. The accuracy in estimates of tc is important; if tc is underestimated the results is an overestimated peak discharge and vice versa.

An underestimate of tc typically leads to an overestimate of peak discharge for the design. The tendency to underestimate the tc is directly related to conservative estimates of design discharges from hydrologic models compared with regional regression equations, as presented in a U.S. Water Resources Council report [11]. The discharge depends not only of the watershed drainage area, but also all other parameters in the watershed, like the watershed slope, mainstream slope, surface roughness, curve number, rainfall and other parameters.

Assessment of Time of Concentration Methods

The tc is affected by weather and geological parameters such as rainfall intensity, curve number, slope, and flow length. Silveira et al (2005) evaluated the performance of 23 formulas for rural and urban catchments and showed that the performance of these formulas for rural catchments is [12] better than that for urban ones. It implies the larger difficulty to estimate time of concentration for urban catchments than rural ones. Numerous formulas to estimate the time of concentration have been developed for different land uses and watershed areas. .Recognizing the importance of time parameters, hydrologists have developed procedures and empirical formulas for estimating time parameters based on very limited data. The table (1) presents a summary of some available tc methods.

METHODOLOGY

The following sections explains the methodology used in this research.

Hydrologic and Hydraulic Studies Analysis

The first step in this research is to analyze a sample of hydrological and hydraulic studies to compare the available tc methods in the literature with the commonly used in Puerto Rico and also verify if they are used correctly for the conditions for which they were created.

Case Study

In this step, a specific watershed is analyzed, to estimate the tc from different methods using as a reference the NRCS velocity method employed in the TR-55 model.

Time of Concentration Calculations

Then, based on the sample of hydrological and hydraulic studies, seven H-H studies were selected to represent the whole sample and analyze if they are used correctly for the conditions for which they were created. Also find the time of concentration values for these seven studies using the most used in Puerto Rico methods and other methods that can be utilized.

Statistical Calculations

The final step of the process is the statistical computations. In order to evaluate, compare and determine a suitable method in this study a ranking based selection procedure will be developed using the time of concentration values obtained from the Hydrologic and Hydraulic studies and compare these values with a reference time of concentration value. The statistical tests

Table 1
Summary of Time of Concentration Methods

Method	Equation	Remarks	Restrictions
Kirpich (1940)	$tc = 0.0078\, L^{0.77} / S^{-0.385}$ L=length of channel ft S=average watershed slope ft/ft	Developed from SCS data for seven rural basins in Tennessee with well-defined channel and steep slopes (3% to 10%) and for areas up to 200 acres (80 ha)	For overland flow on concrete or asphalt surfaces multiply tc by 0.4: for concrete channels multiply by 0.2: no adjustments for overland flow on bare soil or flow in roadside ditches.
Izzard (1946)	$tc = \frac{41.025(0.0007i + c)L^{0.33}}{S^{0.333} i^{0.667}}$ i=rainfall intensity in/h c= retardance coefficient L=length of flow path, ft S=slope of flow path, ft/ft	Developed for overland flow on roadway and turf surfaces. The retardance factor ranges from 0.007 for smooth pavement to 0.012 for concrete and to 0.06 for dense turf.	This method is designed for applications in which the product of the intensity (in/hr) and flow length (ft) is less than 500. The application of the formula requires an iterative solution, since i is dependent on time of concentration.
Federal Aviation Administration (FAA 1970)	$tc = 1.8\,(1.1\text{-}C)\, L^{.50} / S^{.333}$ c=dimensionless runoff coefficient	Developed from airfield drainage data and this method have been widely used for overland flow in urban areas. The length, slope, and resistance variables are for the principal flow path	Valid for small watersheds where sheet flow and overland flow dominate
SCS Lag(1973)	$tc = \frac{100\, L^{0.8}[(\frac{1000}{CN}) - 9]^{0.7}}{1{,}900\, S^{0.5}}$ L = watershed length (ft) S = watershed slope % CN = curve number	The lag equation was developed using data from watersheds ranging in size from 1.3 acres to 9.2 square miles. It spans a broad set of conditions ranging from heavily forested watersheds with steep channels and a high percent of runoff	The watershed area must be less of 2,000.00 acres and small rural watersheds where overland flow dominates. The watershed need to be represented by a weighted CN and the land use must be primarily rural, urban condition cannot be more than 10% of the watershed. The CN must be more than 40 or less than 80 and the watershed slope must be less of 64 percent.
Kinematic Wave Formulas Morgali and Linsley (1965) Aron and Erborge (1973)	$tc = \frac{0.94\, L^{0.6}[n]^{0.6}}{i^{0.4}\, S^{0.3}}$ L=length of overland flow, ft n=Manning roughness coefficient i=rainfall intensity in/h S=average overland slope ft/ft	Overland flow equation developed from kinematic wave analysis of surface runoff from developed surfaces	The method requires iteration since both I and tc is unknown
Kerby (1959) and Hathaway (1945)	$tc = 0.8275\, (LN)^{0.467} S^{-0.233}$ L=length of overland flow, ft N=flow retardance factor S= overland flow path slope ft/ft	Kerby defines the flow length as the straight line distance from the most distant point of a basin to its outlet, measured parallel to the surface slope.	Drainage basins with areas of less than 10 acres and slopes of less than0. 01
SCS average velocity (1975,1986)	$Tc = 1/60\, \frac{L}{V}$ L=length of flow path, ft V=average velocity in feet per second (TR 55)	Overland flow charts of TR 55 show average velocity as a function of watercourse slope and surface cover	

that will be employed in this research to the analyzed data to evaluate and determine suitable model in this research are the mean deviation test (MD), mean difference BIAS), relative error percentage (RE), mean square error (RMSE) with the reference value, as follows:

Relative Error Percentage

$$\left|\frac{Q_0-Q_e}{Q_0}\right| x\ 100$$

Mean Difference (BIAS)

$$\frac{1}{n}\sum_{i-1}^{n}\frac{Q_0-Q_e}{Q_0}$$

Mean Deviation

$$\frac{1}{n}\sum_{i-1}^{n}(Q_0-Q_e)$$

Mean Square Error (RMSE)

$$\left|\frac{1}{n}\sum_{i-1}^{n}\frac{(Q_0-Q_e)^2}{Q_0}\right|^{1/2}$$

Where:

Q_0= observed value

Q_e= estimated value

N= number of samples

RESULTS AND DISCUSSION

Hydrologic and Hydraulic Studies Analysis

The objective in this first step is to analyze a sample of forty hydrological and hydraulic studies to determine the most commonly used formulas for the hydrologists in Puerto Rico. The data set comprises forty hydrologic and hydraulic studies conducted in PR. These hydrologic studies were prepared for the Puerto Rico Highway and Transportation Authority (PRHTA) for different projects like bridge improvements and new constructions. This forty Hydrologic and Hydraulic studies were analyzed and reviewed for the proposed research. During the investigation, the tc methods more utilized by the professionals in PR were found. The three equations more used in Puerto Rico for time of concentration are the NRCS (Natural Resources Conservation Service) velocity method, the NRCS lag method, and the application of empirical equation Kirpich.

The figure 2 shows the methods distribution percentage in the dataset analyzed which is comprised of forty hydrologic and hydraulic studies conducted in PR. From figure2 the most used tc methods in Puerto Rico are the Kirpich method and SCS Lag method, with 35% each one of the whole dataset analyzed. The TR 55 method was used by 22 % of the whole data analyzed. Also an 8% of the analyzed studies estimated the value of the time of concentration.

The figure 3 shows the distribution of the selected sample used along the Puerto Rico Island and its respective methods in the different areas of the country.

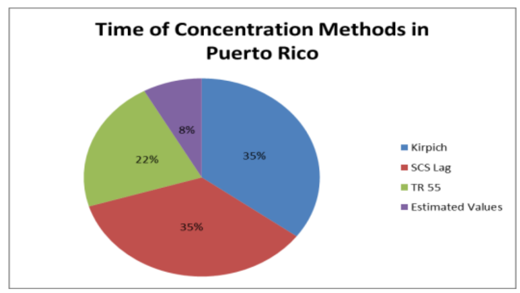

Figure 2
Time of Concentration Methods Percentage Distribution

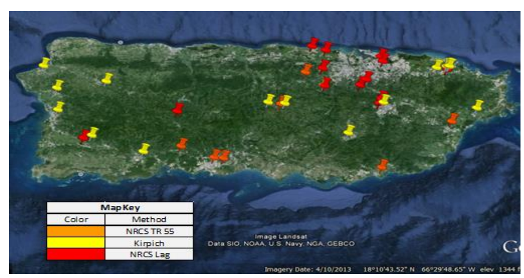

Figure 3
Time of Concentration Methods by Geographic Areas

Once the selected sample of cases of study were analyzed is concluded that the hydrologic studies conducted in Puerto Rico were selected the tc methodology correctly. Instead, some studies are used in formulas that were designed for different characteristics of the watershed having analyzed. For example, for rural watersheds are using a method designed for urbanized watersheds and vice versa.

Case Study

A case study was selected in order to compare the tc calculations from different methods. These hydrologic studies were prepared for the Puerto Rico Highway and Transportation Authority (PRHTA). The selected Case Study is the "Hydrologic and Hydraulic study for bridge over Escarcha creek at PR-861, km 4.6 Toa Alta, Puerto Rico., March 1999, prepared by EA Maldonado Associates for PRHTA project AC086115. The PRHTA is in the process of improving the existing bridge at the road PR 861 over Escarcha Creek at Toa Alta municipality. To properly select the length and height of the new bridge, a HH study has to be performed.

Table2
Description of Watershed 1

Area	596.99
Length of River(ft)	7544
Slope Of River (ft/ft)	0.05
Tc	0.65
CN	83

The purpose of the HH studies was to determine expected flows of the Escarcha Creek watershed during a 100 year storm event and suitable drainage structure opening of the crossing streams with construction of the new bridge. The study included the determination of the hydrologic parameter tc. Table 2 shows the watersheds description. The maximum discharge estimated at the outlet of the watershed for 100 year flood frequency was 3,457 cubic feet per second where the time to peak is 12. 30 hours.

For comparison purposes in this study the computation of this parameter was realized by the three more utilized in Puerto Rico, and also two other methods that can be applied to the tropical watersheds.First, The tc was calculated by the NRCS velocity method equation group where is divided into three classes of flow, including sheet flow, shallow concentrated flow and channel flow, as seen in table 3.

Table 3
Tc Calculations by the TR 55 Method for Watershed 1

H H Study	**Segment 1**	**Segment 2**
Surface description	Pasture	
Manning’s roughness coefficient	0.24	
Flow length, L	300	
Two-year 24-hour rainfall	5	
Land slope, s	0.05	
Travel Time	**0.31760771**	

	Segment 1	**Segment 2**
Surface description (paved or unpaved)	Unpave	
Flow length, L ft	1312	
Watercourse slope, s t/ft	0.075	
Average velocity	1.8	
Tt=L/3600 v	**0.20246914**	

H H Study	**Segment 1**	**Segment 2**
Cross sectional flow area, a ft2	508.59	14187.37
Wetted perimeter, Pw ft	147.59	844.44
Hydraulic radius, r = a/pw Compute rft	3.45	16.8
Channel Slope, s ft/ft	0.0318	0.0167
Manning’s Roughness Coeff., n	0.05	0
V = 1.49 r2/3 s1/2 Compute V ft/s	12.12	25.26
Flow length, L	3608	3936
Tt= L/3600 *V	**0.0826916**	**0.043283188**
Tc (hr)	**0.646051634**	

The Kirpich equation was developed for small, agricultural watersheds. The table 4 shows the tc results calculations with this method.

Table4
Tc Calculations by the Kirpich Method for Watershed 1

Length[ft]	Slope[ft/ft]	Tc [min]	TC [hr]
9156.00	0.050	27.77	**0.46**

The SCS Lag Method is used for rural/suburban area drainage basins where a large segment of the area is rural in character. It is related to the physical properties of a watershed such as area, slope and CN. The selected value for the CN was 83. The table 5 shows the tc results calculation with this method.

Table 5
Tc Calculations by the SCS Lag Method for Watershed 1

Length[ft]	Slope[ft/ft]	S [ft/ft]	Tc [hr]
9156.00	0.050	2.05	**0.74**

The FAA method is one of the most widely used methods. The FAA equation was developed for small, relatively flat catchment areas. This equation is sensitive to the selected value of rational method runoff coefficient selected by the professional. The value selected for this coefficient is .95 based on the surface description. The table 6 shows the time of concentration results calculations.

Table 6
Tc Calculations by the FAA method for Watershed 1

Length[ft]	Slope[ft/ft]	S[ft/ft]	Tc [in]	Tc [hr]
9156.00	0.050		70.058	**1.168**

Then, K/H formula was used to estimate time of concentration for small watersheds where overland flow is an important component of overall travel time. This equation is sensitive to the selected value of dimensionless retardance coefficient selected by the professional. The dimensionless retardance coefficient used is similar in concept to the well-known Manning's roughness coefficient. The value selected for this coefficient is .24 based on the surface description. The table7 shows the time of concentration results calculations.

Table7
Tc Calculations by the Kerby/Hathaway Method for Watershed 1

Length[ft]	Slope [ft/ft]	S [ft/ft]	Tc [hr]
9156.00	0.050	60.476	**1.008**

In the above tc calculations can be appreciated the high variability of the time of concentration values calculated by different methods. Kirpich method yields very conservative obtaining then short times of lag time calculations.

Variations in Time of Concentration Calculations

From the forty H-H studies analyzed initially, seven hydrologic and hydraulic studies were selected to verify the changes in the value of tc calculated by different methods for each different watershed. Then, these values were compared for evaluate the tendency of the time of concentration values. The Table 8 shows the variability tendency of the time of concentration calculations for the seven watersheds analyzed.

Table 8
Summary of Time of Concentrations Calculations

H H Study	Kirpich	Lag SCS	TR 55	FAA	Kerby/ Hathaway
1	0.46	0.74	0.65	1.17	1.01
2	0.42	0.76	0.68	0.98	0.57
3	0.60	1.08	1.21	1.23	1.49
4	0.27	1.03	0.97	0.69	0.92
5	0.30	0.92	0.97	0.77	0.99
6	0.17	0.59	0.99	0.51	0.70
7	0.22	0.95	0.70	0.60	0.60

The figure 4 shows the differences in time of concentration calculations for each watershed. The SCS Lag method and the NRCS velocity (TR 55) method have similar values but the Kirpich method yields very conservative with short times of concentration.

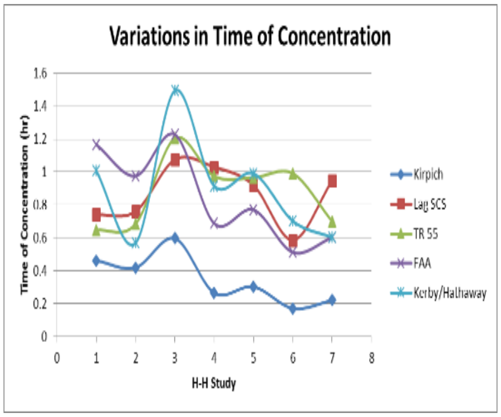

Figure 4
Time of Concentration Calculations Graphically

For the other two method employed in the comparison, the FAA method have similar values to the SCS Lag Method and the Kerby/Hathaway method to the NRCS velocity Method. The values obtained from the NRCS velocity method (TR 55) for the tc are in theory the averages of the tc calculations from the other methods.

Statistical Calculations

To the purpose of evaluate and compare the most used tc methods and others available methods, a ranking based selection procedure was developed. The statistical tests employed in this research to the analyzed data to evaluate and determine suitable model in this research are the mean deviation test (MD), mean difference (BIAS), relative error percentage (RE), mean square error RMSE) with the reference value. For the comparing purposes, the reference tc value is the one calculated with the NRCS velocity method. Although the exact value of tc is not known, in this research is selected the NRCS velocity method as the reference value first because this method was the originally used by the authors in the seven H-H studies analyzed and also some other authors in previous researches used the this method as a reference value. The results of the statistical tests comparing the different methods employed for the tropical watershed 1 with the reference value have been presented in the table 9.

Table 9
Results of Statistical Methods for Watershed 1

Method	MD	BIAS	REP	RMSE	Total
Kirpich	0.53	0.59	58.57	0.59	0.53
SCS	0.02	-0.02	17.62	0.21	0.02
FAA	0.03	-0.02	33.88	0.36	0.03
Kerby	-0.02	-0.02	21.24	0.24	-0.02

Then, the table 10 shows the final Ranking method results. In this selection procedure, the best model is that has the lowest amount of MD, BIAS, RE, RMSE. Based on this, the best method to estimate time of concentration for this watersheds is SCS Lag Method. The FFA method is also a good method to estimate tc in Puerto Rico, although the use of this method is not common among the professionals in Puerto Rico. The Kerby/ Hathaway and Kirpich method have the high amount of MD, BIAS, RE, RMSE.

Table 10
Final Results of Ranking Method of Tc for Watershed 1

Method	MD	BIAS	REP	RMSE	Total
Kirpich	4	4	4	3	15
SCS	1	1	1	1	4
FAA	2	2	2	2	8
Kerby	3	3	3	4	13

Conclusion And Recommendations

Nowadays there is large variability of the formulas used in Puerto Rico and it is important to realize that there is no methodology to distinguish which equation to use for a particular watershed. It is understood that although the time parameter is a critical term, in the practice does not exist a real judge to estimate it. In the majority of cases is hard to judge what time of concentration value is the correct and the professional need to have caution when representing the runoff characteristics of a watershed with one time of concentration. From the results of this research, the computed time of concentration can vary considerably depending on the method employed and it would be wise to use the best method applicable for the characteristics of each watershed. Based on this information, the time of concentration is the hydrological parameter that should be studied more, and the best selection of the method should be done to obtain a better approximation.

This research further illustrated the high variability associated with the time of concentration estimates used as input to rainfall and runoff procedures. The number and sensitivity of input parameters for the NRCS velocity method, FAA, SCS Lag Kerby/and Hathaway make the methods sensitive to decisions made by the analyst. Estimates of required input parameters are heavily dependent on analyst assumptions of hydraulic properties such as channel geometry, runoff coefficient, curve number, etc. That is difficult to measure because of dependence on analyst experience and interpretation. Although the NRCS velocity method is appealing because of its reliance on hydraulics-based estimates of flow velocity, determining the many input parameters necessary requires considerable effort. Based on the statistical tests and the ranking method, the SCS Lag method is the better method to represent the tc for the seven tropical watersheds analyzed. Also an important result of this research, is that the Kirpich method had the lowest values of time of concentrations for the seven watersheds analyzed. This behavior in the Kirpich method results in high peak runoff rates.

In conclusion, based on this research, the relation of lag time and peak flow is inversely proportional so the professional needs to evaluate it. This evaluation its important because an accurate estimates of peak flow magnitudes are necessary for effective structural design and planning purposes. Underestimating peak flows can result in loss of life, costly maintenance, and damage to the water resources. In the other hand, overestimates can result in excessive construction costs of the hydraulic system Based on this research in concluded that In terms of designing for safety and not taking into consideration the economic aspect its preferable that the professional overestimate the peak flow and as a result, its necessary to underestimate the lag time. In this way, underestimating the lag time is the best approximation to have a conservative value and then have the best results in designing by safety.

Future ideas emerge from this research is to perform a sensitivity analysis to better understand the impacts of each parameter within the different time of concentration methods has on the model predictions.

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