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# EVALUATION OF METHODS OF CALCULATION OF CONCENTRATION TIMES AND PEAK FLOW IN HYDROGRAPHIC BASINS: CASE OF RIO PACORA

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#### ABSTRACT

Panama's water resources greatly determine its economic activities. Panama has an average annual precipitation and runoff of 3000 mm and 1764 mm respectively. Concentration and peak times ( $t_p$  and  $t_c$ ) are fundamental parameters for watershed management. However, the equations widely used to calculate these parameters were obtained for areas with different characteristics than those in the tropics. This paper reviews the variability among these equations. As a case study, we use the Pacora River Basin located between the coordinates 8 ° 00 `and 8 ° 20` N and 79 ° 15 `and 79 ° 30` W. It has 6 sub-basins and a total area of 369 km<sup>2</sup>. Its topography is varied, ranging from smooth slopes in the lower part (<8%) to steeper ones in the upper part (up to 75%)  $t_p$  and  $t_c$  were calculated by Kirpich's methods, "Curve Number "Of the SCS and Johnston & Cross.  $T_c$  (hr) values of 6.6, 50.2 and 2.01 and  $t_p$  (hr) of 4.6, 30 and 1.41 were obtained for Kirprich, SCS and Johnston & Cross respectively. In this sense, Kirprich and Johnston & Cross, may be the most appropriate, since the SCS method fits better with basins under 800 Ha. Total  $t_p$  and  $t_c$  values resulted from the summatory of  $t_p$  and  $t_c$  sub-basins values. As a conclusion, there is a necessity in tropical basins to have more monitoring and controlled experiments in order to validate existing methodologies.

Keywords: Pacora River Basin, Panama, Concentration times, Peak flows.

#### 1. INTRODUCTION

Panama is a country with extensive water resources that largely determine its economic activities. (Espinosa et al., 1997). It contains the second largest water supply in Central America with a per capita volume of 52,437 m3 (CCAD, 2005). Its climate is dictated by its position, orientation, narrowness, the influence of the intertropical convergence zone and the interactions of the ocean with the atmosphere (ETESA, 2007). For the period from 1971 to 2002, Panama had an average annual precipitation of 2924 mm (220.8 km3) and an average runoff of 1764 mm (4222 m3 / 133.2 km3), which translates into a runoff coefficient of 60.3% (PHI, 2008). Panama is divided into three rainfall regions: Pacific, Atlantic and Central. The Pacific region has a dry season that runs from December to April, and a rainy season that runs from May to December. For the Atlantic region, precipitation continues throughout the year (ETESA 2007). This precipitation feeds 500 rivers and 52 basins (ANAM, 2011), which are classified in the Pacific and Atlantic slopes. The Pacific basins represent greater water resources and main channels longer than those of the Atlantic basins. (ANAM, 2011)

This research concentrates in one of the Pacific basins, the Pacora River. Its aim is to compare different methods to calculate the concentration and peak times of this basin in order to evaluate both the variability and applicability of these equations, and have a better knowledge of the effects of extreme events in this basin. Concentration and peak times were calculated by different methods in order to know the difference between them and to determine the impacts that extreme rains have on a hydrographic basin. There are a large number of methods for calculating concentration times (Ven Te Chow, 1994, Li and Chibber, 2008). However, three commonly used methods were chosen in this study: i) The Kirpich equation (1940), ii) The equation proposed by the SCS within the "Curve" method Number "(Soil Conservation Service, 1964, 1972), and iii) The" Johnston and Cross "equation (1949)

### 2. THEORETICAL MODELS

This section explains the main components and background of the methods employed to calculate the concentration times and/or peaks in the Pacora river basin. The definition of peak time corresponds to the time in

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which a maximum runoff response is obtained in the river. Concentration time is defined as the time taken by a drop from the furthest point of the basin to reach exit the basin.

### 2.1. Kiprich formula

This formula was developed by Kirpich (1940) for six drainage basins of agricultural land up to 80Ha (0.08 Km2). (Ramser, 1927) However, it is commonly used for watersheds up to 26 km<sup>2</sup> (10 Mi<sup>2</sup>), so this limitation should be considered in the scope of the results obtained. This method is based in the following equations:

$$t_c = 0.00033L^{0.77}S^{-0.385}$$
(1)  
$$t_p = 0.7t_c$$
(2)

Where  $t_c$  and  $t_p$  are the concentration and peak times respectively, both in minutes (min). L is the maximum stream length in m (from the furthest point). and S is the slope H / L where H is the elevation difference between the most remote point of the basin to the basin exit point. It is important to emphasize the difference between both the concepts of tc and tp.

# 2.2. Concentration time from the SCS

Another equation used for calculating  $t_c$  is the one from the Soil Conservacy Service of the United States (SCS), which will be used as part of the CN method (Ven Te Chow, 1994).

$$t_c = \frac{1080 \, L^{0.80} [(1000 / CN) - 9]}{1900 S^{0.50}} \tag{3}$$

Where L is given in Km. CN is the "Curve number" and it is a function of the maximum potential retention of the soil, tc is given in hours. To calculate CN, consider:

- a. Hydrological soil group (HSG). This parameter indicates the runoff potential of a soil. It is divided into four groups (SCS, 1972) ranging from Group A that includes high rates of infiltration and water transmissivity to Group D that corresponds to very low infiltration and transmissivity rates
- b. Previous humidity condition (PHC). The PHCII condition corresponding to an average condition is usually used.
- c. Hydrological condition and slope. The hydrological condition is defined as good or bad depending to the use that is given to it in terms of crop rotation, grazing, and plowing. On the other hand, the slope is classified into five categories according to the criteria established by Sprenger, 1978, ranging from Category I (S <1%) to Category V (S> 20%)

#### 2.3. Johnston and Cross

This formula developed in 1949 for rural areas between (64.7 and 4206 km<sup>2</sup>) relates  $t_c$  in minutes with the basin length (L) and the Slope (S), so It fits very well in terms of area to the Pacora river Basin. It is expressed as:

$$t_c = 300L^{0.5}S^{-0.5} \tag{4}$$

# 3. METHODOLOGICAL MODEL

# 3.1. Basin and sub basins under study

This basin is located between the coordinates 8°00 'and 8°20' of latitude north and 79°15 'and 79°30' of longitude west. It is identified as basin 146, of the regional basin system of Central America. It has a total area of 370 km<sup>2</sup> and a main stream length of 48 km. (http://www.hidromet.com.pa/cuencas.php) It is widely used for recreational and supply purposes. Its topography is varied and depends on the area. Thus, in the lower part there are gentle slopes that do not exceed 8%. In the highlands, on the contrary, we can find slopes up to 75%. In the middle part, slopes can reach up to 35% (Garcia and Valdés, 2009). The characteristics making up these sub basins are shown in Table 1.

Table 1. Wain characteristics of the Paco	ra river sub-basins.			
Name	Main stream length	Sub-basin length	Area	-
	(Km)	(Km)	(Km²)	_
Highlands Pacora river sub basin	23.00	16.0	96.8	-
Indio river sub basin	8.54	8.5	30.0	
Midland and lowlands Pacora river sub basin	24.00	22.6	102.2	
Cabobre river sub basin e	17.40	16.8	94.8	
Tataré river sub basin	15.00	16.0	45.9	
Pacora river basin	47.00	34	369.7	-

# Table 1. Main characteristics of the Pacora river sub-basins

### 3.2. Cálculo de tiempos de concentración y pico

#### 3.2.1. Kirpich formula

Topographic characteristics of the sub-basins were obtained by employing maps as shown in Figure 2. The results of these calculations are shown in Table 2.



Figure 1. Basin and sub basin of the Pacora river.

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**Figure 2.** Examples of the maps used to obtain topographic features in the Pacora river sub basins. (A. Pacora river highlands Sub basin and, B. Indio river sub basin.)

Table 2. Main characteristics of the Pacora river sub bas	sins
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	Stream length	Further point dist to stream	Total length	Area	Upper elev.	Lower elev	S	tc	tp
Sub basins	(Km)	(Km)	(Km)	(Km²)	(m)	(m)	(%)	(hr)	(hr)
Indio river	8.54	2.08	10.66	30.0	580	100	5.62	1.3	0.9
Highlands Pacora river	23.00	2.39	25.39	96.8	840	100	3.22	3.1	2.2
Midland and lowlands Pacora river	21.30 <sup>b</sup>	3.60	24.90	102.2	520	0	2.08	3.4	2.4
Cabobre river	17.40	2.11	19.51	94.8	860	20	4.83	2.1	1.5
Tatare river	15.00	3.07	18.07	45.9	520	20	3.33	2.3	1.6

#### 3.2.2. Curve Number calculation (CN)

Table 3 shows the land uses for the Pacora River sub basins. This information is an input for the calculation of CN. For the entire basin a hydrological soil group B was assumed, which corresponds to soils with moderate water transmissivity and infiltration rates under very humid conditions.

### Table 3. Land use for the Pacora river basin and sub basins in area percentages.

Sub basins	IF	MF	OU	St	Ag	SuAg	PFV	Total
Indio river	18.1	21.8	0.0	14.5	0.0	45.6	0.0	100
Highlands Pacora river	19.4	52.8	0.0	8.6	0.0	19.3	0.0	100
Midland and lowlands Pacora river	12.8	2.8	0.3	16.8	43.7	22.9	0.7	100
Cabobre river	16.1	26.5	0.0	13.2	5.7	38.4	0.0	100
Tatare river	28.7	4.8	0.1	10.4	41.8	14.1	0.0	100

IF: Intervened Forest, MF: Mature Forest, OU: Other uses, St: Stubble, Ag: Agriculture, SuAg: Subsistance Agriculture, PFV: Prone to flood Vegetation

Tables 4 and 5 presents for each sub basin the necessary factors for the determination of CN: hydrological condition, slope and the Hydrological Soil Group (HSG). The previous moisture condition (PMC) was assumed as II (average). Table 6 shows the resulting CN values by land use and sub-basin. With these values and the percentages in table 3, average CN values for each sub-basin were calculated (See Table 7)

#### Table 4. Factors to consider for CN calculations

				Fa	actors to	o consider			
Sub basins			Hydro	ologic c	onditior	۱		Slong	ЦСС
-	IF	MF	OU	St	Ag	SuAg	PFV	- Slope	130
Indio river	R	G	-	R	Р	G	Р		G
Highlands Pacora river	R	G	-	R	Р	G	Р	II	G
Midland and lowlands Pacora river	R	G	-	R	Р	G	Р	П	G
Cabobre river	R	G	-	R	Р	G	Р	П	G
Tatare river	R	G	-	R	Р	G	Р	П	G

Hydrologic Condition  $\rightarrow$  G = Good, R= Regular, P= Poor.

#### Table 5. CN values classified by slope-HSG and hydrological condition-HSG

Sub basins	İF	MF	OU	St	Ag	SuAg	PFV
	Hydrologi	ical con	dition-H	SG			
Indio river	60	55	84	86	61	79	-
Highlands Pacora river	60	55	84	86	61	79	-
Midland and lowlands Pacora river	60	55	84	86	61	79	-
Cabobre river	60	55	84	86	61	79	-
Tatare river	60	55	84	86	61	79	-
	S	Slope-HS	G				
Indio river	70	70	-	-	64	82	10
Highlands Pacora river	66	66	-	-	61	79	5
Midland and lowlands Pacora river	66	66	-	-	61	79	5
Cabobre river	66	66	-	-	61	79	5
Tatare river	66	66	-	-	61	79	5

### Table 6. Resulting CN values

Sub basins	IF	MF	OU	St	Ag	SuAg	PFV
Indio river	65	62	84	86	64	82	10
Highlands Pacora river	63	60	84	86	61	79	5
Midland and lowlands Pacora river	63	60	84	86	61	79	5
Cabobre river	63	60	84	86	61	79	5
Tatare river	63	60	84	86	61	79	5

### Table 7. CN values by sub basins

Sub cuencas	CN X Area (%)							011
	IF	MF	OU	St	Ag	SuAg	PFV	CN
Indio river	11.8	13.5	0.0	12.5	0.0	37.4	0.0	75
Highlands Pacora river	12.2	31.7	0.0	7.4	0.0	15.2	0.0	66
Midland and lowlands Pacora river	8.1	1.7	0.2	14.4	26.7	18.1	0.0	69
Cabobre river	10.1	15.9	0.0	11.4	3.5	30.3	0.0	71
Tatare river	18.1	2.9	0.1	8.9	25.5	11.1	0.0	67

# 3.2.3. Johnston and Cross

The  $t_c$  and  $t_p$  values obtained with this equation are shown in Table 8. The values for S and L employed in these calculation were obtained from Table 2.

Table 8. tc and tp values employ	/ing the equ	ation from Joł	unston and Cross.
	S	tc	tp

	S	tc	tp
Sub basins	(ft/mile)	(hr)	(hr)
Indio river	297	0.67	0.47
Highlands Pacora river	243	1.00	0.70
Midland and lowlands Pacora river	121	1.71	1.20
Cabobre river	262	1.00	0.70
Tatare river	164	1.23	0.86
Total	130	2.01	1.41

# 4. RESULTS

# 4.1. Kirpich Formula

A peak flow time in the Pacora river of 4.6 hours was obtained by employing two calculation approximations. First, by adding up  $t_p$  values (from table 2) for the upper and medium/lower sub-basins, and second by applying equations 1 and 2 to the entire basin. For the latest approach we used a L value equal to 50.29 Km (addition of the Stream lengths of the critical route) and a slope of 0.017. This slope was calculated by employing an elevation of 840 m, corresponding to the furthest point of the upper Pacora river basin.

# 4.2. SCS method

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In Table 9, we show  $t_c$  and  $t_p$  values for each sub basin. Also, by employing the CN values and area estimates for each sub basin (Table 2), a weighted average for CN equal to 71 was estimated for the Pacora basin.

·		Parameters		
Sub basin	CN	S	t₀ (hr)	t <sub>p</sub> (hr)
Indio river	75	5.62	5.8	3.5
Highlands Pacora river	66	3.22	23.9	14.3
Midland and lowlands Pacora river	69	2.08	24.2	14.5
Cabobre river	71	4.94	12.8	7.7
Tatare river	67	3.47	15.8	9.5

Table 9. t <sub>c</sub> and t <sub>n</sub>	values emp	oloying the	SCS equation	on.
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Similar to the case of the Kiprich equation, the critical route is defined by the sum of the times corresponding to the upper Pacora River basin and the Middle and Lower Basin (the basin is employed here, not the river stream since this equation has area considerations, which Kiprich does not have). Thus from this method, we obtain a  $t_p$  equal to 28.8 hours. If we apply equation 3 directly for the whole basin, assuming a CN of 71 and an average slope (S) of 0.017 (1.7%), same as the one calculated for Kirpich, we get a  $t_p$  equal to 30.0 hr.

#### 4.3. Johnston and Cross.

Repeating the above procedure, for Johnston and Cross a  $t_p = 2.71$  hours was obtained. If we apply equation 4 directly for the whole basin, and assuming an L = 34 Km (21.2 Mi). which corresponds to the route of the furthest point from the upper Pacora River basin. (elevation 840 m), and a final elevation of 0, and an S = 130 feet / miles, a value of 2.01 hours is obtained

#### 4.4. Comparison of models.

Table 10 shows the results obtained by the different methods employed. As expected, each one of them gave different results. However, we consider Kirprich and Johnston & Cross, may be the most appropriate for this basin. Kirprich because it is commonly used for smaller rural basins, and Johnston & Cross because it is model based on basins with area ranges within the Pacora scale. In the case of the SCS method, it is more applicable for basins of up to 800 Ha (Ven te Chow, 1994), even though it has the advantage that in the calculation of the CN, general aspects of topography, and land use are evaluated. It was also observed a small difference in the calculation of the concentration and peak times, using the basin as a whole or adding times from the critical route formed by main streams within the Pacora sub-basins. This addition was carried out under the logic that both Kirprich and to a greater extent the SCS method were developed for small basins, hence working at sub-basins level could improve the results accuracy.

Sub basins	Kirprich		SCS		Johnston / Cross	
	tc (br)	t <sub>p</sub> (hr)	tc (br)	t <sub>p</sub> (hr)	t <sub>c</sub> (br)	t <sub>p</sub> (hr)
Indio river	1.3	0.9	5.8	3.5	0.67	0.47
Highlands Pacora river	3.1	2.2	23.9	14.3	1.00	0.70
Midland and lowlands Pacora river	3.4	2.4	24.2	14.5	1.71	1.20
Cabobre river	2.1	1.5	12.8	7.7	1.00	0.70
Tatare river	2.3	1.6	15.8	9.5	1.23	0.86
Pacora combined	6.6	4.6	48.1	28.8	2.71	1.90
Pacora as a whole	6.6	4.6	50.2	30.0	2.01	1.41

Table 10. Values of t<sub>c</sub> and t<sub>p</sub> values using different calculation methods

#### 5. CONCLUSIONS

The existing empirical models for the estimation of the concentration and/or peak time were developed based on information from specific basins. Therefore, the use of a particular model must be done considering the characteristics of the basin to model with those employed originally by these models. In this work, we found little difference among concentration times, if this parameter was calculated by employing the basin as a whole or as the sum of sub-basin times within a critical flow path. Finally, It will require greater monitoring effort and the development of controlled experiments in basins with different areas, and characteristics to establish or validate already existing models and formulas. This is even more urgent in Tropical Basins, since historically these basins have been less studied and have less instrumentation than those in temperate zones.

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