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Engineering Design Parameters Of Storms In Venezuela

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Abstract. This research deals with hydrologic analysis to estimation engineering design parameters of storms in Venezuela, which help hydrologists to improve their environmental designs. This analysis focus on storm advancement coefficient **r** (SAC) to establish storm pluviographs; Intensity Duration Frequency (IDF); and Area - Depth – Duration relationships (ADD). Based on the analysis of 275 storm events, values of **r** were calculated obtaining a mean value of 0.41 and a standard deviation of 0.075, and being 61 , 30 and 9 % of the storms from the advanced, retarded and symmetric type respectively. Rainfall data of 162 recorders spread all over the country were used for the IDF analysis, using nevertheless instead traditional analysis a model that allows to estimate peak rainfall/intensities for any duration and frequency based on the General Equation for Hydrologic Frequency Analysis (GEHFA), in conjunction with a transform function that linearize the mass curve of the accumulated rainfall amounts and the method of minimum squares to estimate the parameters of the GEHFA: mean, μ, and standard deviations of the rainfall extremes. The results are given as equations for μ and σ; correlation coefficients are higher than 0.99. Based on the analysis of 47 storms occurred on Northeast, Andes, Central and Central West regions of Venezuela, lineal models for Area Reduction Factors as function of D were developed, with correlation coefficients values over 0.980. Design rainfall hyetographs are built base on estimated **r** values and the established IDF model. Furthermore, Area Reduction Factor models can be used to reduce rainfall point values.

Key words: Storm analysis, storm design, hydrologic design, advancement coefficient, IDF Analysis, area reduction factor

1. Introduction

Traditional hydrologic methods for the environmental design of storm sewers and road culverts, as the rational method, use only the peak discharge and need for their application values of the storm intensities for different frequencies and durations. The modern design techniques of hydrologic systems requires the knowledge of precipitation patterns as the system input to calculate the rates of flow using any rainfall-runoff and flow routing procedures. The design storm is defined by a hyetograph or by an isohyetal map. In regions with scarce rainfall records the precipitation patterns have to be constructed using the general characteristics of the surrounding area. Furthermore, for small basins area reduction factors have to be applied to derive design rainfall over the basin on the basis of point data.

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The storm advancement coefficient is a good tool to represent the design storm distribution pattern to be used in connection with the Intensity Duration Frequency analysis (IDF) to estimate the magnitude of the rainfall design parameter of any hydraulic project. Area reduction factors can be estimated from Area - Depth – Duration curves.

This research deals with estimations for Venezuela of advancement coefficient **r** to be used for establishing storm pluviographs, modeling of Intensity- Duration- Frequency (IDF) curves that allow the estimation of peak rainfall/intensities for any duration and frequency; and estimation of area reduction factors to be used in small basins hydrologic projects.

2. Theoretical Fundaments

The storm advancement coefficient **r** (SAC) is defines as the ratio of the time before the peak t_a to the total storm duration T_d (Guevara and Cartaya, 1998; Guevara, 2000; Guevara, 2002 b):

$$r = t_a / T_d \tag{1}$$

The recession time t_b is defined as the time from the peak to the end of the storm:

$$t_b = T_d - t_a = (1 - r)\, T_d \tag{2}$$

Values of r = 0,50 mean that the peak rainfall intensity occurs in the middle of the storm. Values of $r < 0.50$ and $r > 0.50$ indicate that the peak happens earlier and later respectively; in the first case the storms are said to be from the advanced type and in the second case, the storms are from the retarded type.

Knowing the total precipitation depth, P, in the hyetograph and the duration of the storm, T_d (base length of the triangle), the intensity distribution of the storm can be adapted to a triangular shape and following relations can be established:

$$P = T_d\, h/2 \tag{3}$$

$$h = 2 P / T_d \tag{4}$$

Where h is the high of the triangle.

To get a reliable estimation of design hyetographs two methods are available:

Alternative Block Method uses an IDF-Curve, specifying the precipitation depth occurring in n successive time intervals of duration t over a total duration $T_d = n\ t$. The rainfall intensity is read from the IDF - curve for the selected return interval for each of the durations t, 2 t, 3 t, 4 t... The corresponding precipitation depth is calculated as the product of the intensities and the duration. The amount of precipitation for each additional unit of time t is equal to the difference between successive precipitation values. These increments are called blocks and are register into a time sequence setting the maximum intensity value at the middle of the total duration and the rest of the blocks are arranged in descending order alternately to the right and left of the central block forming in this way the desired design hyetograph.

Instantaneous Intensity Method. If the IDF - curve is defined by a mathematical expression, equations can be developed for the time variation of the storm intensity in the design hyetograph. The precipitation depth for a duration period T_d around the storm peak is equal to the value given by the ID-curve or the corresponding equation. The precipitation intensity is considered to vary continuously along the storm. Imaging an alternative block rainfall distribution with a symmetrical triangle shape, it could be assumed that the intensity at the left side of the triangle (concentration time) can be represented as $I_a = f(t_a)$ and the intensity at the right side (recession time) as $I_b = f(t_b)$. A given precipitation intensity *I* will intercept the hyetograph at t_a to the left and at t_b to the right of the peak Based on that supposition it can be shown that in generally:

$$I = C\,T^x / (D + b)^n \qquad (5)$$

where I is the average maximum rainfall intensity; T is the period of return, C, x, b and n are parameters of the equation to be fitted.

To construct the IDF curves the Gumbel I distribution has been standardized in Venezuela, which simplified by the Chow Frequency Factor Method has following expression:

$$I_T = \mu_I + \sigma_I K_T \qquad (6)$$

μ_I and σ_I are the mean and standard deviations of I to be modeled, and K_T is the Frequency Factor, tabulated in standard hydrology books as a function of return period T, length of records, and the probability distribution function (in this case Gumbel Type I). For large periods of records, the value of K_T can be calculated as follows:

$$K_T = -(6/)\{0.5772 + \text{Ln}\,[\text{Ln}\,T/(T-1)]\} \qquad (7)$$

On other side, the parameters μ_I and σ_I are related with the Duration D as follows (Guevara and Cartaya, 2001; Guevara, 2002 a; Guevara, 2002 c) :

$$P/D = \mu_I\ (\text{or}\ \sigma_I) = 1/(A + B\,D) \qquad (8)$$

where A and B are parameters to be adjusted.

Knowing the regression parameters of equations (8), they can be used in connection with equations (5), (6) and (7) to estimate the Intensity of a design storm for a given Duration and Frequency.

Regarding Area-Depth-Duration analysis, Court (1961) proposed a gaussian model to compare the results of ADD of different studies. Renard and Brakensiek (1976) reported marked variations between the results different models used to discuses the storm characteristics in the western intermountain region of USA.. Nicks and Igo (1980) found that the area rainfall distribution in the Southern Great Plains, USA, do not meet the adjustment requirements existing models for other areas. Furthermore, many models are not sensitive to the variation of Depth-Area relation with the variation of storm duration; and therefore they developed a mathematical model to relate to mean depth of rainfall over a given area to storm center rainfall depth. The model is based on the observation that the depth of mean rainfall decreased with distance from the storm center and that the rate of reduction of the point amount increased with shorter duration of rainfall at the storm center. Experience from fitting individual storm depth – area curves lead to the following form of the model to calculate the mean rainfall covering a given area for a given duration:

$$P_A = P_P - [P_P \, A \, D^m] / [a + b \, A] \tag{9}$$

Where P_A is the mean rainfall depth in millimeters for area A in square kilometers; P_P is the storm center point amount in millimeters; D is the duration of the storm center rainfall in hours; and ; and m, a, and b, are regression parameters (for Souther Great Plains: $m = -0.1478$; a = 337.4767; y b = 1.0935; adjusted from rainfall data of 138 stations).

Based on the analysis of 50 storms registered in the pluviometric national network, former Ministry of Public Works found that the duration of design storms in Venezuela varies generally between three and six hours, and that the reduction factor R_D due to area influence is given as (Guevara y Cartaya, 1992):

$$R_D = 100(P_A / P_P) = m \, e^{-A/n} \tag{10}$$

Where R_D is the reduction factor of the storm of durations D in hours; A is the rainfall cover area in square kilometers; e is the base of natural logarithms; and m and n are adjustment parameters varying with the duration as follows: For D = 1, 3, 6 hours: m = 95.40; 96.70; 97.40; n = 1337,00; 1904,00; 3449,00, respectively.

Applying the mathematical concept that the inverse function of the accumulated rainfall amounts with the duration is a linear function, in this paper following alternative model of those given in Equations (9) and (10) is proposed:

$$Y = 1 / P_A = 1/[a + b A] \tag{11}$$

where a and b are adjustment parameters.

By definition, point rainfall P_P is the rainfall value corresponding to a cero area; i.e. 1/a in Equation (11). Thus, the reduction factor R_D is given by following relation:

$$R_D = P_A / P_P = a / [a + b A] \tag{12}$$

The analysis of available data in Venezuela shows that this general model (Equation (12)) can be applied individually for each storm duration, establishing as many lineal relations as durations exist. Furthermore, regression parameters a_D and b_D are exponential functions of D, as follows:

$$a_D , b_D = c D^{- d} \tag{13}$$

where c and d are parameters to be adjusted.

3. Methodology

For the advancement coefficient **r**, a total of 275 independent storm events of different durations were selected using the rainfall registers of 20 stations operated by the Agency of Environ and Renewable Natural Resources (MARNR) and by the Air Force of Venezuela. The basic storm characteristics for each selected event were determined: time of begin and end of the storm, total rainfall depth and rainfall intensity for intervals of 5, 10, 15 and 30 minutes. The storm hyetographs and the storm mass curves for each selected event were calculated for time intervals of 5, 10, 15, and 30 minutes. On the basis of the hyetographs and the mass curves the triangular rainfall distribution a long the storm were calculated. On the basis of the triangular hyetographs the advancement storm coefficient was calculated applying equation (1) for each selected event. A variance analysis homogeneity test for the fitness of the advancement storm coefficients for the whole country was pursued.

For the IDF modeling the storm events of different durations were selected using the rainfall registers of 162 stations. IDF - curves for each station were elaborated. Regression parameters A and B for both, mean intensities and standard deviation, were calculated applying relation (8).

On the basis of rainfall data of 47 storms AAD curves were constructed (Table 5). Available storm durations were 1,2,3,4,5,9,and 12 hours, with 38,34,34,4,47,15, and 6 storm events respectively. Applying Equations (11) and (12) correlation and regression coefficients were calculated for the proposed individual and general model.

4. Discussion Of Results

Statistically speaking, all the analyzed storms can be considered to be from the advanced type with a representative mean value of 0.410 for **r** in the whole country and a standard deviation of 0.075 (Table 1 and 2).The mean value of **r** in each station varies between a maximum of 0.535 and a minimum of 0.218. About 61 % of the analyzed storms are from the advanced type (minimum value 0.213); 23 % are from the retarded type (maximum value 1.00); 16 % are from the symmetric type. The high intensity long duration storms do not follow a defined morphologic pattern; they vary from one station to an other, but also for the same station along the time duration. Only a few events of that kind fit to a triangular shape distribution; the majority of them show a bimodal distribution. The short duration storms, on the contrary, show a triangular shape for the rainfall distribution along the storm duration, with small variations due to secondary effects of the storm duration, station location and measurement errors.

Regarding IDF Modeling values of A range for the mean intensity from a minimum of 0.0399 to a maximum of 2.3405 with a mean value of 0.3775 and a standard deviation of 0. 2287 (Table 3). The mean value of B is 0.0157, varying from a minimum of 0.0076 to a maximum of 0.0376; the standard deviation is 0.0052. The correlation coefficient is very high, always higher than 0.904. For the standard deviation of intensities, A varies between 0.2205 and 4.0870 with a mean value of 1.3648 and a standard deviation of 0.6180; the value of B ranges from 0.0006 to 0.1631; the mean values is 0.0434 and the standard deviation is 0.0217. The correlation coefficients is almost always bigger than 0.9400; only in a few cases the correlation coefficient is smaller than 0.80. The standard error of estimates is for the mean intensities less than 10 % in 64 % of the stations; less than 20% in 92 % of the cases; and less than 30% in 96 % of the stations; only in 4 % of the cases the error is bigger than 30%; the weighted mean of the error is around 11 %.The estimation errors of standard deviation are a little bigger: only 15 % of the cases show errors less than 30%; the error of estimates is less than 60 % in 61 % of the analyzed cases, and less than 90 % in 80 % of the stations; 20% of the cases show errors bigger than 90%; the weighted mean of the error is about 28 % (Table 4).

The results of correlation and regression analysis for ADD curves are given in Table 5. The regression parameters a_D , and b_D tend to diminish slightly as D increases; but this tendency is only evident until D riches 6 hours; after that the variation is almost imperceptible. Taking into account that duration of design storms in Venezuela are rarely bigger than 6 hours, the developed model constitutes a useful tool for designers, at least for preliminary designs. The values of correlation coefficients are supremely height , even for four and 12 hours durations with only four and six storm events respectively. Using the figures given in Table 5, following relations were obtained for the regression parameters aD and bD, and for the reduction factor:

$$a_D = 0.0258\, D^{-\,0.471}\ ;\ \text{with}\ \ r = -\ 0.805 \qquad (14)$$

$$b_D = 2 \times 10^{-5}\, D^{-\,0.7749}\ ;\ \text{with}\ \ r = -\ 0.789 \qquad (15)$$

$$R_D = 1\ /[1 + 7.75 \times 10^{-4}\, D^{-\,0.304}\, A \qquad (16)$$

6. Conclusions And Recommendations

Statistically speaking the storms in Venezuela are from the advanced type with a mean value for the advancement storm coefficient of 0.410 and a standard deviation of 0.075 (Table 2). The short duration storms follow a triangular rainfall distribution pattern. The long duration storms, on the contrary, show a variable behavior with a bimodal distribution pattern. For preliminary studies the mean value of **r** can be used to estimate the precipitation hyetograph of the storm design in the whole country. According to the importance of the project the designer is free to adopt the most unfavorable value of **r**. As soon as more information is available the study should be extended to other stations and isolines of **r** could be drawn in order to search for **r** the feasibility of regionalization.

An IDF Model for Venezuela has been developed, to be used to estimate the parameter of the design storm intensity (mean and standard deviation) to be applied in connection with the Chow General Frequency Equation for a given period of recurrence. For the case of the mean value data fitted to the model have a correlation coefficient of 0.999 and a mean standard error of estimates of 11 %. For the standard deviation the correlation coefficient is 0.990 and the standard error of estimates is 28 % (Table 3 and 4). It is farther recommended to review the results of the analysis as soon as enough and reliable new information is available.

The correlation analysis of ADD curves shows that correlation coefficients are height enough to allow the use of obtained relations for preliminary studies in the country.

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Table 1. Storm advancement coefficient mean values for the design precipitation hyetographs with indication of the number of storms n in each station and the standard error for r.

Station name	Number of storms, n	Mean value for r	S = $2S/n^{1/2}$
1 Puerto Ayacucho	13	0.507	0.159
2 Barcelona	9	0.481	0.153
3 Guasdualito	16	0.367	0.115
4 Base Sucre	12	0.392	0.178
5 El Limón	21	0.411	0.097
6 Rancho Grande	23	0.410	0.091
7 Barinas	7	0.453	0.144
8 Ciudad Bolívar	15	0.401	0.106
9 Bejuma	16	0.486	0.099
10 Campo Carabobo	20	0.468	0.093
11 El Cambur	18	0.361	0.078
12 Valencia Fer.	14	0.400	0.123
13 Valencia Aer.	7	0.452	0.123
14 Cachinche	15	0.538	0.099
15 Calabozo	19	0.341	0.068
16 Mérida	15	0.355	0.092
17 Maiquetía	8	0.400	0.110
18 Porlamar	7	0.218	0.057
19 Acarigua	7	0.458	0.156
20 Mene Grande	13	0.307	0.082
Total	275	—	
Mean Value	13.8		0.111
Standard deviation S	5	0.410	0.032
		0.075	

Table 2. Storm advancement coefficient for the design precipitation hyetographs for each station with indication of the type (advanced r_a and retraded r_r
.

Station	r_a	N_a	$2S/n^{1/2}$	r_r	N_r	$2S/n^{1/2}$	$N_{r = 0.50}$
1	0.295	6	0.118	0.758	6	0.144	1
2	0.233	3	0.169	0.812	2	0.125	4
3	0.243	11	0.080	0.732	3	0.090	2
4	0.213	8	0.098	0.916	3	0.140	1
5	0.254	12	0.067	0.716	5	0.104	4
6	0.284	16	0.044	0.733	6	0.090	1
7	0.354	5	0.075	0.700	2	0.200	0
8	0.240	8	0.039	0.800	2	0.141	5
9	0.279	5	0.153	0.720	4	0.104	7
10	0.295	10	0.058	0.699	7	0.085	3
11	0.273	13	0.045	0.646	3	0.046	2
12	0.245	8	0.081	0.820	2	0.140	4
13	0.350	4	0.125	0.634	2	0.066	1
14	0.350	7	0.028	0.736	6	0.108	2
15	0.266	15	0.046	1.000	1	0	3
16	0.250	10	0.060	0.610	3	0.061	2
17	0.327	6	0.069	0.619	2	0.096	0
18	0.218	6	0.057	1.000	1	0	0
19	0.237	3	0.164	0.665	3	0.089	1
20	0.285	12	0.075	0.571	1	0	0
Number of cases		168			63		44
%		61.1			22.9		16
Mean Value	0.276	8.4		0.744	3.2		2.2
S	0.047	3.8		0.120	1.9		1.9

Table 3. Summary of the correlation and regression analysis of rainfall records in Venezuela.

Parameter	For Mean Intensity	For Standard Deviation
A	Min.: 0.0399 Max.: 2.3405 Mean: 0.3775 St.D. : 0.2287	0.2205 4.0870 1.3648 0.6180
B	Min.: 0.0076 Max.: 0.0376 Mean: 0.0157 St.D.: 0.0052	0.0006 0.1631 0.0434 0.0217
R	Min.: 0.90371 Max.: 0.99994 Mean: 0.9990	0.02876 0.99960 0.9500
St. Error of Estimates	Min.: 0.01201 Max.: 0.78832 Mean: 0.1074	0.07157 5.13000 0.28200

Table 4. Summary of results for the IFD - Analysis of storms in Venezuela

Parameter	For Intensity μ_I in mm/h	For Standard Deviation $_I$ in mm/h	Model for μ_I / $_I$ (D in minutes)
A	0.520	1.809	[60/ (A + B D)]
B	0.016	0.044	
R	0.9990	0.990	
St. Error (%)	11	28	

Table 5. Results of correlation and regressiona análisis applied to ADD curves of storms in Venezuela (second number of each block in colum 2 and 3 is the corresponding standard deviation)

Storm Duration in hours	A_D parameter	B_D parameter	Correlation coefficient *R*	Numbers of events	Observations
1	0.0277 0.0166	0.00002401 0.00001874	0.9817	38	
2	0.0181 0.0108	0.00001286 0.00000845	0.9839	34	
3	0.0140 0.0072	0.00000950 0.00000700	0.9873	34	
4	0.0141 0.0401	0.00000677 0.00000427	0.9975	4	
6	0.0100 0.0044	0.00000528 0.00000382	0.9855	47	
9	0.0103 0.0042	0.00000465 0.00000393	0.9844	15	
12	0.0124 0.0044	0.00000238 0.00000162	0.9847	6	