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Effect of interception by canopy in the IDF relation (rainfall intensity, duration and frequency) in a semiarid zone

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This study has been developed on a semiarid zone located in Mexico; the objective of this research is to measure rainfall interception, and to evaluate the effect of interception in intensity, duration, frequency curves. The rainfall interception was determined from rainfall simulation at several intensity levels on grass covered vegetation samples taken from experimental zone, where income precipitation, runoff, change in soil water storage and soil drainage were measured, with these, water balance for events of simulated rainfall on covered vegetation were performed. From maximum rainfall in 24 h intensity-duration-frequency relationships (IDF) of rainfall for return period of 2, 5, 10, 20 and 50 years is obtained, evaluating the interception effect on those curves when establishing four sceneries of different coverage.

Key words: Rainfall interception, intensity-duration-frequency curves, water balance, rainfall simulation, rural hydraulic structures.

INTRODUCTION

Interception is defined as the amount of water retained by leaves, branches and trunks, and the amount of water retained by plant residues on the soil surface (Groen and Savenije, 2006; Gerrits et al., 2006). This amount is evaporated back into the atmosphere along with the measure of water evaporated by the soil and transpired by plants to form the total amount returned to the atmosphere (Chow et al., 1998; Tucci, 2001). The interaction between rain drops and canopies changes the microphysical characteristics of precipitation. Understanding the mechanisms driving these changes is a key step towards unveiling the mechanics of soil water recharge, soil erosion, and evaporation of intercepted rainfall (Moraes and Krajewski, 2013).

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It is also important to mention that the architecture of the tree is mostly responsible for the way interception occurs during a rainfall event, altering interception percentages and time (Wani and Manhas, 2012).

The interception of rainfall by vegetation is an important process in the hydrological cycle and has been the subject of research for several decades. Researchers have intensified investigations of the contribution of the water balance components (Steidle et al., 2011). Characterizing the response of a catchment to rainfall, in terms of the production of runoff vs the interception, transpiration and evaporation of water, is the first important step in understanding water resource availability in a catchment. This is particularly important in small semi-arid catchments, where a few intense rainfall events may generate much of the season’s runoff (Love et al., 2010).

Interception greatly affects the hydrology; this was proven by an investigation conducted in Spain, comparing the rainfall of a canopy area, and a deforested area. The results show that the canopy area had both smaller peak flows and smaller low flows than the deforested catchments; most rainstorm events produced almost no discharge response; the intensity of precipitation had no influence on the magnitude of peak flows; and depth to the water table was the most important factor in the relationship between precipitation and discharge. These results confirm that forest conservation reduces floods and soil erosion, particularly on steep slopes. (Serrano-Muela et al., 2008).

In order to study the interception phenomenon there are several methods, an investigation conducted shows that the method used for canopy interception strongly affects how rainfall is partitioned between canopy evaporation and troughfall (Mao et al., 2011). Some of them are:

The introduction of micro-droplets of crushed raindrops during rainfall. The aerodynamic diffusion and transfer of both vapor and micro-droplets from canopy to upper air was described and calculated, and proposed formulas applied to eight rainfall events at the Okunoi Experimental Station, Tokushima, Japan (Hashino et al., 2010). Another method is using mechanical displacement sensors to distinguish from interception, storage and evaporation (Van et al., 2011). Yet another method was developed in 2006, using earth observation images to estimate local quantitative values of rainfall interception loss. Leaf Area Index (LAI) and fractional vegetation cover per grid cell are important process variables for rainfall interception. These two variables are estimated from images using spectral vegetation indices and using spectral mixture analysis, respectively (Jong and Jetten, 2007). A new method that uses 3-D digitized data to simulate rainfall interception and distribution has been developed showing very precise results (Bassette and Bussiere, 2005). However, the most used method for estimating interception according to a study is the Gash's analytical model (Wang et al., 2013). Note that while Gash´s model is the most used, there has to be a previous study to determine which model is the more convenient to apply to a set of data (Muzylo et al., 2009).

Now, it is also important to clarify that not all the interception process occurs in the canopy section, there is also interception on the mulched fields that affects the water balance. A study was conducted to investigate the effects of pebble size in China. Interception increased with pebble cover percentage but decreased with pebble size (Li et al., 2005). Interception is then followed by evaporation in most scenarios, so a study in California using monitored 5 min intervals rainfall, and it was determined that 46% of the interception loss occurs in post-storm evaporation, while 54% is evaporated during the storm (Reid and Lewis, 2009).

Importantly, most studies related to the interception have been developed in forests with cold, temperate and tropical climates (Rodrigo and Ávila 2001; Loescher et al., 2002; Raat et al., 2002; Gerrits et al., 2006), whereas these have been scarce in semi-arid and arid environments because of the difficulty of applying methodologies to quantify the phenomenon in shrub and herbaceous species. These difficulties have justified the use of rainfall simulators under controlled conditions to estimate the amount of intercepted water in arid and semi-arid environments (Belmonte, 1997; Belmonte and Romero, 1998; Carlyle-Moses, 2004; García–Estringana et al., 2006).

Some of the most relevant studies conducted include: A rainfall interception study in Oakland, to determine the partitioning of rainfall and its chemical composition on 3 different trees. Resulting in interception percentages of 27, 25.2 and 14.3% (Xiao and McPherson, 2011). Another study conducted in Japan was developed, where rainfall interception on bamboo was studied, showing a wide range of interception percentages according to the intensity (Onozawa et al., 2009). A simulation experiment in a laboratory with interception datasets of events with different intensities was performed, quantifying the rainfall intensity per leaf unit, obtaining results with precision of 91.5% (Anzhi et al., 2005). Another study performed in Kenya, consisted in measuring rainfall interception losses from 33 months, using the Gash´s model with very precise results (Jackson, 2000).

The estimated of hyetographs and hydrographs in many watersheds often confronts the problem of lack of information because there are not enough hydrometric and meteorological stations. In order to lessen the problems mentioned above, in the drafting of rural and hydraulic infrastructure projects, different empirical methods are used to deem hyetographs and hydrographs from scant information, standing out for its simplicity the rainfall intensity-duration-frequency (IDF) curves. However, in the creation of the curves it is not very usual to concern about the interception (Keim et al., 2004), which can cause an oversizing of the hydraulic infrastructure. This is one reason why it is important to highlight the effect of interception on rainfall IDF curves. This paper's main objective is the estimation of the rainfall interception by the herbaceous vegetation using the simulation of rainfall method in a semi-arid region and its effect on the IDF curves.

LITERATURE REVIEW

Interception is defined as the amount of retained rainfall or stored temporarily by vegetation and can be evaporated after or during the rainfall event (Savenije, 2004). The quantity and dynamics of the interception process depends on the characteristics and structure of the vegetation and some rain features: intensity, duration, shape, direction, angle and distribution of drop size as well as other variables such as the temperature and wind speed (Schowalter, 1999; Crockford and Richardson, 2000; Schellekens et al., 2000). The systematic study on the interception begins with Horton in 1919 who separates soil evaporation from water evaporation (once the event) stored by the tree surface saturation. The author expresses canopy interception loss (EI) as follows (Gash, 1979; Belmonte, 1997; Belmonte and Romero, 1998):

$$EI = \int_{0}^{t_T} E\,dt + S \tag{1}$$

Where E is the evaporation of intercepted water during rainfall, S, the canopy capacity, t is the time and t_T is the duration of the rainfall event. Evaporation from trunks is neglected and is not considered into the equation.

Based on the approach of Horton (1919) physical and analytical models have been developed for the study and modeling of the interception process based on the assumption that vegetation acts as a reservoir (Rutter et al., 1971; Gash, 1979), and other numerical and stochastic models (Mulder, 1985; Calder, 1990; Keim et al., 2004). The grass and woody vegetation and the vegetable waste product of the natural senescence are considered as a water reservoir which is filled by rainfall and emptied by evaporation and drainage. Canopy interception loss (EI) on the rainfall event is estimated by a mass balance considering evaporation is negligible during the event. The resulting equation is:

$$EI = P - (\Delta S + R + D) \tag{2}$$

Where P is the income precipitation; R, the runoff; ΔS, the change in soil water storage and D, the soil drainage. The analysis of rainfall in a region requires a probability distribution over time. In particular, it has been argued that the maximum rainfall is satisfactorily well described by a Gumbel distribution (Villón, 2006). The cumulative distribution function is:

$$F(x) = \exp\left[e^{-\alpha(x-\mu)}\right] \quad ; \quad -\infty < x < \infty \tag{3}$$

Where $0 < \alpha < \infty$ is the scale parameter; $-\infty < \mu < \infty$, the positional parameter or mean. The derivative of the distribution gives the probability distribution function or density function.

Regarding the IDF curves it is quite common to use the methodology proposed by Cheng (1983), Campos and Gómez (1990) and Aparicio (2008). In this proposal, the rain which lasts an hour and a payback period of two years or more can be evaluated by relating it to a 24 h rain with the same return period, called rain ratio / length (R). This ratio is calculated using the formula:

$$R = \frac{P_1^{Tr}}{P_{24}^{Tr}} \tag{4}$$

Where P_1^{Tr} and P_{24}^{Tr} correspond respectively to 1-hour-rain and 24-hour-rain with return period (Tr) of two or more years.

The methodology also requires calculating the ratio of rain/return period (x):

$$X = \frac{P_t^{100}}{P_t^{10}} \tag{5}$$

Where P_t^{100} and P_t^{10} are the 24-hour-rain and return eriod of 100 years and 10 years respectively.

Cheng's equation to estimate rainfall at different durations (t), and return periods (Tr) is:

$$P_t^{Tr} = \frac{aP_1^{10}\log\left(10^{2-X}Tr^{X-1}\right)t}{60(t+b)^c} \tag{6}$$

Where P_1^{10} is the rain of 1-hour-duration- rain and return period of 10 years, in millimeters, (a), (b) and (c) are regional parameters that depends on the ratio (R).

MATERIALS AND METHODS

To evaluate the amount of water intercepted by the herbaceous vegetation, a semi-arid region bordering the states of Guanajuato and Queretaro has been selected, which has the Centro Experimental Norte de Guanajuato (CENGUA) weather station at National Institute of Forestry, Agriculture and Livestock Research and (INIFAP). The average altitude is about 2000 m, with an average annual temperature of 16.7°C and maximum 38°C and average annual rainfall of 550 mm. The flora feature is the heath, where tree individuals are seen as wild cherry (*Prunus serotina*), mesquite (Prosopis spp.), Peruvian pepper (*Schinus molle*) and some shrubs such as acacia (Acacia spp.) coyotillo (*Karwinskia humboldtiana*) and granjeno (*Celtis pallida*) (National Center for Municipal Development, Government of the State of Queretaro, 1999).

Table 1. Initial volumetric water content and storage

Box 1			Box 2			Box 3			Box 4		
θo	Δθ	ΔS	θo	Δθ	ΔS	θo	Δθ	ΔS	θo	Δθ	ΔS
0.330	0.149	14.92	0.314	0.165	16.51	0.335	0.144	14.42	0.318	0.161	16.13
0.290	0.189	18.93	0.278	0.201	20.14	0.310	0.169	16.92	0.265	0.214	21.42
0.394	0.085	8.52	0.381	0.099	9.87	0.380	0.099	9.92	0.349	0.130	13.01
0.330	0.149	14.92	0.360	0.120	11.97	0.399	0.080	8.01	0.344	0.135	13.52
0.295	0.185	18.46	0.334	0.145	14.51	0.389	0.090	8.98	0.310	0.170	16.97
0.260	0.220	21.97	0.259	0.220	22.02	0.270	0.210	20.97	0.269	0.210	21.02
0.270	0.209	20.92	0.269	0.210	21.02	0.280	0.199	19.92	0.280	0.200	19.97

Quantification of the interception by the herbaceous vegetation was carried out with a rainfall simulator, for which representative samples of this vegetal cover were extracted, composed by herbs, grasses, shrubs, crop residues and a substrate of sandy loam soil. The unaltered samples are placed in steel boxes with dimensions of 40 × 50 cm with a thickness of 10 cm.

To estimate the intercepted volume by the herbaceous vegetation by hydrological balance, it is necessary to measure the different components, the simulated rainfall is measured by rain gauges placed between the boxes in order to verify that the simulated intensity was approximately equal to that of the region under study, which is in a range of 30 to 50 mm/h. Simulations were performed on one hour period.

Each box has a chute to quantify surface runoff or runoff volume, so it is necessary to quantify the volume of water stored in the soil substrate to separate the volume intercepted by vegetation and the volume absorbed by the soil. The film stored in saturated conditions is calculated using the formula:

$$\Delta S = \left(\theta_s - \theta_0\right) P \tag{7}$$

Where P is the thickness of the substrate, θ_0 and θ_s are the volumetric water content and initial saturation, respectively. This is calculated with $\theta_s = \left(\rho_t / \rho_w\right) \omega_s$, where ρ_w is the density of water; ρ_t, the dry soil density and ω_s, the gravimetric content at saturation, or it can be estimated from the total soil porosity calculated with the classical formula $\phi = 1 - \rho_t / \rho_s$, where ρ_s is the particles density, generally considered equal to the density of quartz particles: $\rho_s = 2.65\ \mathrm{g/cm^3}$.

The base of each box is drilled to retain the drained volume during the rainfall simulation; drainage water is observed at about fifty minutes. For this reason, it was selected one hour as rainfall simulation time to measure the drained volume for ten minutes. Finally, the total intercepted water in an hour is estimated using the Equation (2).

To obtain the IDF curves it is necessary to analyze the information of the weather station of CENGUA. In this particular case, the analysis contains the series of maximum monthly rainfall data in 24 h with rain gauge registered over 16 years to form the time series of maximum rainfall events for each year. To show the effect of the intercept component of the IDF curves, the number of years was considered adequate. Gumbel distribution is applied on this series in order to obtain the corresponding maximum rainfall for estimated following Cheng (1983) methodology already discussed, set return periods. IDF curves for rainfall in the study region are in Equations (4) to (6).

RESULTS AND DISCUSSION

There have been seven simulations of rain on the herbaceous vegetation in four boxes. To calculate the storage contents it is assumed that the dry soil density has an average $\rho_t = 1.38\ \mathrm{g/cm^3}$ value, giving a total porosity of $\phi = 0.479\ \mathrm{cm^3/cm^3}$. The average volumetric water content at saturation is $\omega_s = 0.342\ \mathrm{g/g}$ and therefore $\theta_s = 0.472\,\mathrm{cm^3/cm^3}$. The absolute difference $\left|\phi - \theta_s\right| = 0.007\,\mathrm{cm^3/cm^3}$ indicates that at the end of rainfall events the soil was almost saturated, so it is reasonable to assume that the volumetric water content at saturation is equal to total porosity. The values of initial moisture content of each rainfall event are reported in Table 1. The storage contents are reported using the Equation (7) and the value of the thickness of the substrate is $P = 100\ \mathrm{mm}$.

On Table 2 income precipitation is reported in each event and in each box, so is the runoff and the soil drainage. The blades intercepted as calculated with Equation (2), are reported in the same table. The relation between rainfall and the interception by the herbaceous vegetation in each rainfall event, and in each box is shown in Figure 1; the linear model yields high values of the coefficient of determination R^2 of rainfall in the range studied, in Table 3. Figure 1 shows the linear trend lines have similar characteristics in three boxes, in box 1, although the slope is similar to the other three, the intercept is only just lower because in due that in this box the density of grass cover is slightly lower compared visually with respect to the other three.

Furthermore, in can be observed that at greater magnitude and intensity of rainfall events, vegetation tends to intercept a greater percentage of rainfall. Other authors report a similar behavior (Xiao and McPherson, 2011; Hashino et al., 2010; Onozawa et al., 2009). This is because the architecture of the tree is mostly responsible for the way interception occurs during a rainfall event, altering interception percentages and time. Due to the possible spatial variability of rainfall interception by herbaceous vegetation in the region under study, and also due to the lack of extensive studies of this

Table 2. Components of water balance and calculation of the Interception loss.

	Box 1				Box 2				Box 3				Box 4			
P	R	D	ΔS	EI	R	D	ΔS	EI	R	D	ΔS	EI	R	D	ΔS	EI
30.00	11.92	2.88	14.92	0.28	10.93	2.30	16.51	0.26	4.02	11.18	14.42	0.38	3.28	10.18	16.13	0.41
31.00	8.24	3.63	18.93	0.20	6.75	3.65	20.14	0.46	3.01	10.55	16.92	0.52	3.30	5.58	21.42	0.70
32.00	13.71	9.40	8.52	0.37	14.79	6.70	9.87	0.64	11.05	10.50	9.92	0.53	5.48	12.90	13.01	0.61
34.00	13.00	5.59	14.92	0.49	13.49	7.90	11.97	0.64	9.90	15.35	8.01	0.74	4.99	14.78	13.52	0.71
36.00	5.55	11.20	18.46	0.79	12.66	8.14	14.51	0.69	11.74	14.58	8.98	0.70	8.28	10.12	16.97	0.63
43.00	14.50	5.50	21.97	1.03	14.00	6.10	22.02	0.88	5.35	15.50	20.97	1.18	5.95	15.00	21.02	1.03
48.00	16.00	9.85	20.92	1.23	15.75	9.80	21.02	1.43	10.74	16.00	19.92	1.34	10.60	16.00	19.97	1.43

*Units in millimeters.

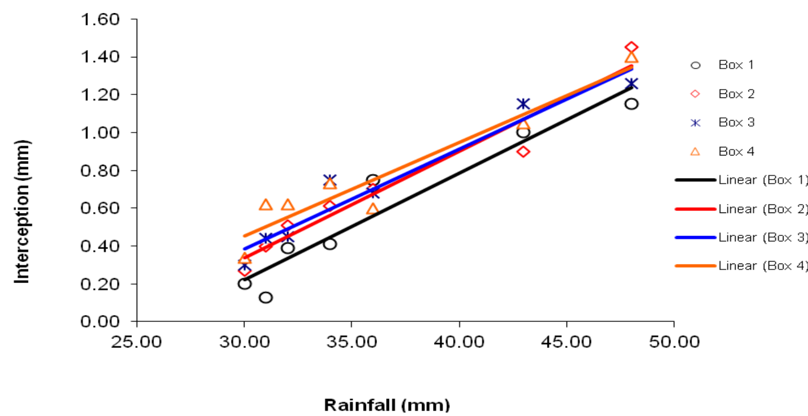

Figure 1. Relationship between interception and rainfall in the seven simulation events and in each repetition (measured in the four boxes).

phenomenon, the obtained relation between interception and rainfall can be used in its regional analysis. This analysis can be simplified if a linear regression model between interception and rainfall in the experiment is made. Intercept values obtained in each box are averaged in each of the seven rainfall events (Table 1). The average values of the intercept for each rainfall event and linear regression model are shown in Figure 2.

The line equation is:

$$EI = 0.0522P - 1.1681 \quad (8)$$

With a coefficient of determination $R^2 = 0.9867$, higher than those for the partial models, due to the smoothing process of the data. It is important to clarify, that these equations are calculated using the dominant values of the zone of study, the equation has been bounded, restricting it to rainfall values between 30 to 48 mm. In order to forecast interception values with the proposed model in Equation (8) it is recommended that the aforementioned rainfall range of values is used, because the predominant rainfall magnitudes and intensities of the maxima precipitation events in the studied area are in the previously mentioned range. Therefore extrapolation with values below

Table 3. Equations for estimating herbaceous vegetation interception

Box	Equation	R^2
1	EI = 0.0564P - 1.4704	0.92
2	EI = 0.0565P - 1.3572	0.94
3	EI = 0.0528P - 1.1968	0.94
4	EI = 0.0495P - 1.0309	0.91

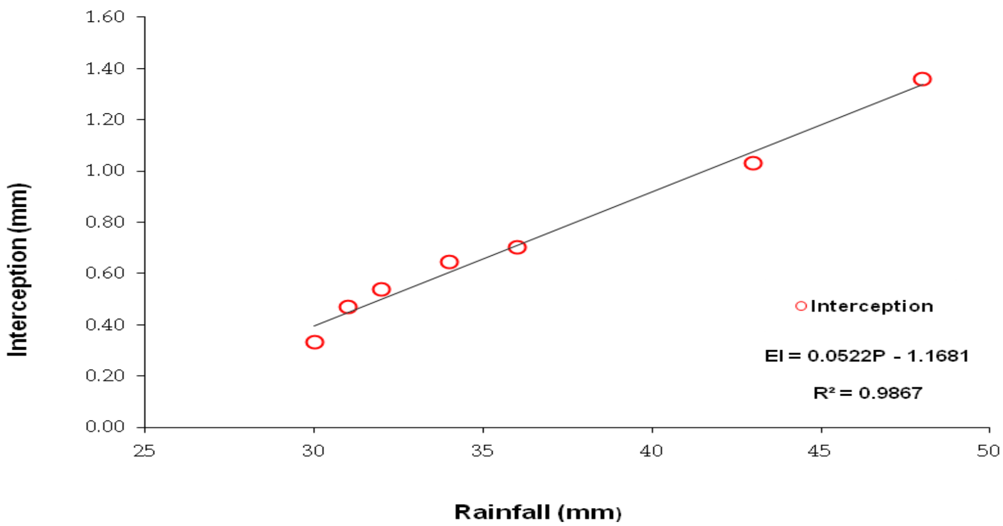

Figure 2. General model of the interception component of the herbaceous vegetation.

30 mm and above 48 mm is not recommended.

To analyze the effect of the interception of grass and trees vegetation cover on the relation IDF of rainfall, in addition to Equation (8) which relates the interception of herbaceous vegetation to rainfall, it is necessary the corresponding equation to timberline interception. The obtained relation in the study region is as follows (Mastachi-Loza, 2007):

$$EI = 0.2005P + 1.2783 \quad (9)$$

On the basis of maximum observed rainfall in 24 h, (Table 4) Equations (8) and (9) are used to estimate the interception by herbaceous vegetation (EI_H) and tree vegetation (EI_A). The net precipitation shown in Table 4 are calculated with $P_H = P - EI_H$, $P_A = P - EI_A$ and $P_{H+A} = P - EI_{H+A}$, with $EI_{H+A} = EI_H + EI_A$; the percentages of interception $p_H = (EI_H/P) \times 100$, $p_A = (EI_A/P) \times 100$ and $p_{H+A} = (EI_{H+A}/P) \times 100$ are also shown; and outlines four scenarios in which the IDF curves obtained from previous rainfall, described as follows:

Scenario 1: The IDF curves are drawn from the observed maximum rainfall in 24 h (P).

Scenario 2: The net precipitation herbaceous (P_H) is taken into account for the IDF curves.

Scenario 3: IDF curves are developed from the net tree rainfall (P_A).

Scenario 4: net grass precipitation (P_H) and net tree rainfall (P_A) are used to build the IDF curves.

Once IDF curves are obtained for each scenario, one can evaluate the effect of the intercept component of the relation. The data from the four rainfalls shown in Table 4 conforms to the Gumbel distribution, Equation (3). Table 5 shows the corresponding values of the parameters of the distribution, as well as the values of the parameters in the chi-square test (χ^2). The calculated values are definitely lower than the theoretical values at two levels of probability, validating the Gumbel distribution to estimate rainfall at different return periods.

Table 6 shows the maximum rainfall in 24 h and net precipitation recorded for six return periods calculated through Gumbel distribution using $1/Tr(P) = 1 - F(P;\alpha,\mu)$. Rain/duration ($R$) and rain/return period (x) ratios are obtained by applying Equations (4) and (5) respectively, both are reported in Table 7; these ratios also show the parameters (a), (b) and (c) , which describe the place and

Table 4. Maximum rainfall in 24 h, net rainfall and interception rates for the IDF curves.

Years	Rainfall for llthe IDF curves				Percentages intercepted by the ground cover		
	Maximum P. 24 h	Net Herbaceous P.	Net Arboreal P.	H + A net P.	% Herbaceous Intercepted	% Arboreal Intercepted	% H + A Intercepted
1986	38.3	37.47	29.34	28.51	2.17	23.39	25.56
1987	34.5	33.87	26.30	25.67	1.83	23.76	25.59
1988	36.4	35.67	27.82	27.09	2.01	23.56	25.57
1989	38.7	37.85	29.66	28.81	2.20	23.35	25.56
1990	41.2	40.22	31.66	30.68	2.38	23.15	25.54
1991	55.8	54.06	43.33	41.59	3.13	22.34	25.47
1992	37.3	36.52	28.54	27.76	2.09	23.48	25.57
1993	37.0	36.24	28.30	27.54	2.06	23.51	25.57
1994	55.8	54.06	43.33	41.59	3.13	22.34	25.47
1995	42.2	41.17	32.46	31.43	2.45	23.08	25.53
1996	53.2	51.59	41.25	39.65	3.02	22.45	25.48
1997	29.4	29.03	22.23	21.86	1.25	24.40	25.65
1998	41.2	40.22	31.66	30.68	2.38	23.15	25.54
1999	58.4	56.52	45.41	43.53	3.22	22.24	25.46
2000	41.4	40.41	31.82	30.83	2.40	23.14	25.54
2001	55.4	53.68	43.01	41.29	3.11	22.36	25.47

P: Rainfall in milímeters, H: Herbaceous Vegetation, A: Arboreal Vegetation.

Table 5. Gumbel distribution parameters compared to chi-square probability levels of 99.5 and 99%.

Max. P. 24 h			Net herbaceous P.			Net tree P.			H + A net P.			Probability levels	
α	μ	χ^2	α	M	χ^2	α	μ	χ^2	α	μ	χ^2	$\chi^2_{0.995}$	$\chi^2_{0.99}$
0.14	39.23	2.52	0.15	38.25	2.33	0.18	30.06	2.09	0.19	29.06	1.89	32.80	30.60

Table 6. Maximum rainfall (mm) observed in 24 h and net precipitation for the studied covers and their return periods Tr.

Tr (years)	Max. P. 24 h	Net herbaceous P.	Net Arboreal P.	Net H+A P.
2	41.85	40.73	32.15	31.02
5	49.94	48.40	38.62	37.07
10	55.29	53.47	42.90	41.07
25	62.06	59.89	48.31	46.13
50	67.08	64.65	52.32	49.88
100	72.06	69.37	56.30	53.61

the ratio functions (R), these parameters are obtained using the proper graph by Chen (1983), called relationship between parameters (a), (b) and (c) of a standard storm and the ratio of 1 h rain to 24 h rain, (Campos and Gómez, 1990).

Rain for different durations (t), and return periods (Tr) are calculated with the Equation (6), then millimeters rainfall are converted into top intensities in (mm/h); usually the IDF relation is graphically represented with the length on x-axis and intensity on the y-axis, showing a series of curves for each of the periods of return (Tr); in Figures 3 to 6, there are IDF curves for each scenario stated above, they show the decrease in intensity as a result of interception of rainfall. Table 8 shows the hourly intensities for each scenario and return period (Tr), it also shows the effect of the interception in the IDF relation by percentage, the variation of the intensity at each stage is due to the storage water intercepted by each of the vegetations.

Table 7. Rain/duration ratios (R), rain/return period (χ) and parameters (a), (b) and (c), which are of place and ratio functions (R).

Max. p. 24 h					Net herbaceous p.					Net arboreal p.					Net H+A P.				
R	**X**	**a**	**b**	**c**	**R**	**X**	**A**	**B**	**c**	**R**	**X**	**a**	**b**	**c**	**R**	**X**	**a**	**b**	**c**
0.60	1.30	39.9	11.7	0.87	0.61	1.30	40	11.8	0.88	0.59	1.31	38	11.2	0.86	0.58	1.31	37.3	11.1	0.85

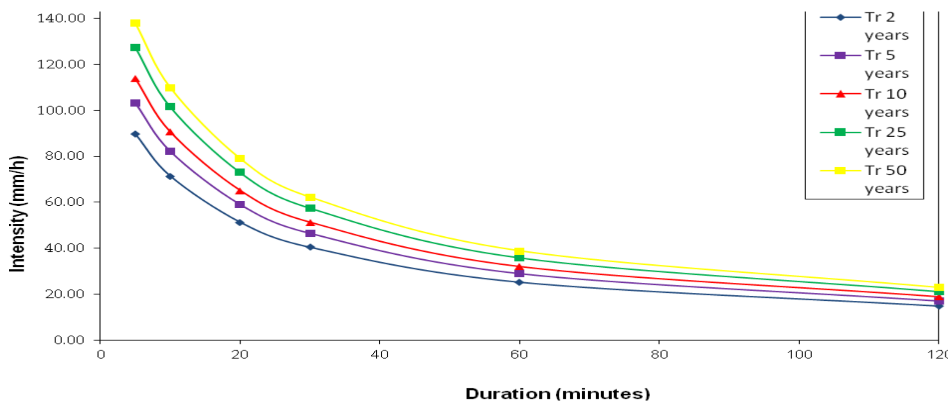

Figure 3. Intensity-duration-frequency curves without interception effect (scenario 1).

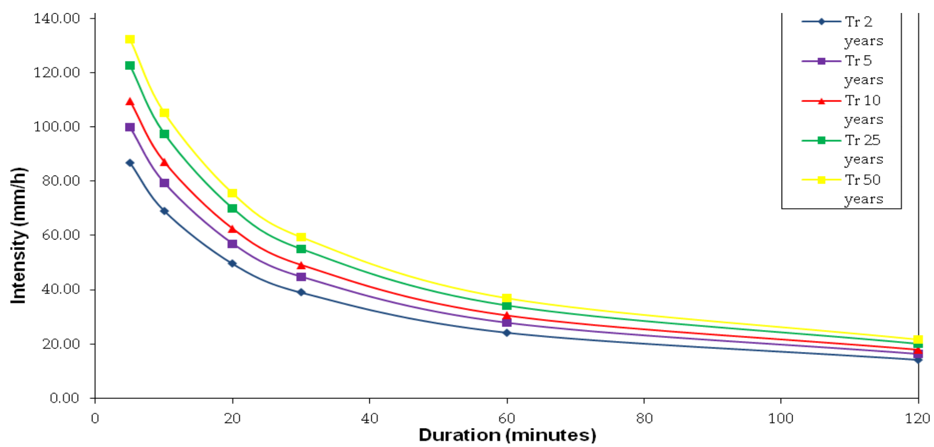

Figure 4. Intensity-Duration-Frequency curves with herbaceous vegetation effect (scenario 2).

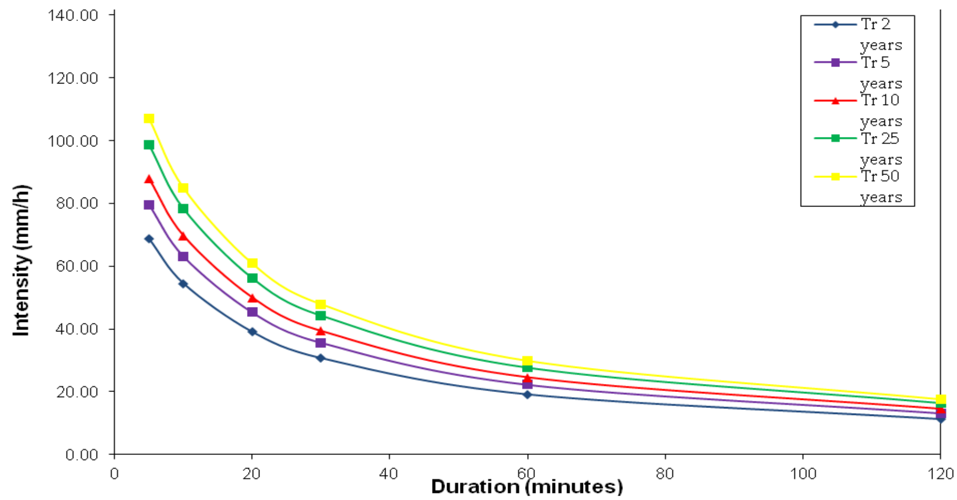

Figure 5. Intensity-Duration-Frequency curves with arboreal vegetation effect (scenario 3).

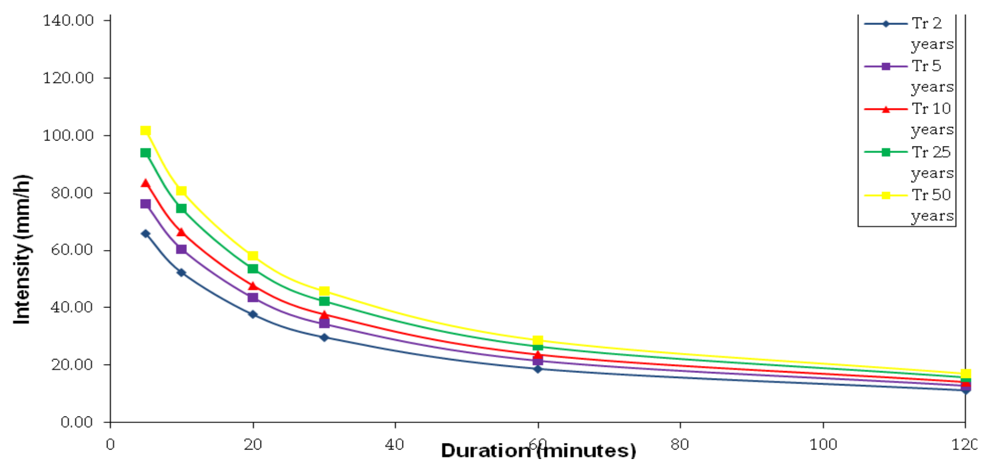

Figure 6. Intensity-Duration-Frequency curves with arboreal and herbaceous vegetation effect (scenario 4).

Table 8. Maximum hourly intensities for each scenario consisting of different plant covers.

Tr (years)	Maximum intensity at IDF curves (mm/h)				Effect (%)		
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 2	Scenario 3	Scenario 4
2	25.24	24.19	19.22	18.64	4.16	23.86	26.15
5	29.11	27.80	22.27	21.52	4.48	23.47	26.06
10	32.03	30.54	24.59	23.70	4.67	23.24	26.01
25	35.90	34.15	27.64	26.58	4.87	23.00	25.95
50	38.82	36.88	29.95	28.76	4.99	22.84	25.92
				Mean	4.63	23.28	26.02

Application

By means of an application it is possible to see the effect of the intercept component of the IDF relation at the basin. Basin is chosen for the Peña Colorada protected natural area located in the region; it has an area of 35.06 km^2, which 0.65% is bare eroded soil, 92.73% is comprised of woody vegetation, and 6.63% is herbaceous

Table 9. Effect of intercept runoff from a watershed.

Surface	Cover (%)	Area (km^2)	Runoff coefficient for a 2 years Tr	Intensity without the effect of interception (mm/h)	Intensity with the effect of interception (mm/h)	Flow (m^3/s)	Flow (m^3/s)
Bare ground	0.65	0.23	0.36	17.00	17.00	0.39	0.39
Tree and scrub	92.73	32.51	0.29	17.00	12.00	44.56	31.45
Herbaceous	6.63	2.32	0.34	17.00	16.00	3.74	3.52
					∑	49.00	35.00

vegetation and grasslands. Intensities are determined for a return period of 2 years and a concentration time of 89 min. Rational method is applied for the determination of flows as reported in Table 9.

Table 9 shows the effect of the intensity interception component for a set return period; the greatest impact occurs when there is a vegetal tree cover scenario, where the intensities obtained from the IDF curves with this condition are lower than those obtained with a bare soil condition, where the effect of vegetation is not considered. This represents the traditional use of the IDF curves. Regardless of the interception there is a total flow of 48.68 m^3/s, otherwise the flow is reduced to 35.36 m^3/s. This represents a 28%, which is a significant percentage when sizing a hydraulic structure.

Conclusions

The intercept of the semi-arid herbaceous vegetation in proportion to rainfall equals 3%, a value that promotes global understanding of the component, and is useful for calibration and validation of hydrological models. Four conditions or scenarios have been stated to use the IDF curves; any effect is found for the scenario without vegetation; for the scenario set by interception in herbaceous vegetation there is a 5% of average in intensity reduction values; the intercept in tree cover has an effect of 23%; the biggest effect on the curves or IDF relation of the rainfall is reached considering a scenario consisting of herbaceous and tree vegetation, common in most watersheds, with a 24% in intensity values. Because of this, design intensities may be different according to scenario or present or deemed cover, causing thereby that the design flows to increase or decrease, causing a reflected impact in the economic costs of a rural hydraulic. Furthermore the above considerations may be important in the integrated management of water resources in a rural area, which may be reflected in the determination of volumes of water to supply towns, agricultural irrigation and drainage sizing.

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REFERENCES

Anzhi W, Jinzhong L, Jianmei L, Tiefan P, Changjie J (2005). A semi-theoretical model of canopy rainfall interception for Pinus Koraiensis Nakai. Ecol. Mod. 184:355-361.

Aparicio MFJ (2008). Fundamentos de hidrología de superficie. México. D.F, *Editorial Limusa*. P. 304.

Bassette C, Bussiere F (2005). 3-D modelling of the banana architecture for simulation of rainfall interception parameters. Agric. Forest. Meteorol. 129:95-100.

Belmonte SF (1997). Interceptación en bosque y matorral mediterráneo semiárido: balance hídrico y distribución de la lluvia neta. Tesis doctoral, Universidad de Murcia. P. 375.

Belmonte SFY, Romero DA (1998). Modelos y técnicas en interceptación. *Cuaderno*s técnicos de la S.E.G. no 11, Geoforma, Ediciones Logroño.

Calder IR (1990). Evaporation in the uplands. J. Wiley (Ed) Chichester.

Campos ADF, Gómez DR (1990). Procedimiento para obtener curvas I-D-Tr a partir de registros pluviométricos. Revista Ingeniería Hidráulica en México. V(2. II Época):39-52.

Carlyle-Moses DE (2004). Throughfall, stemflow, and canopy interception loss fluxes in a semi-arid Sierra Madre Oriental matorral community. J. Arid. Environ. 58:181-202.

Chen C (1983). Rainfall intensity – duration – frequency formulas. J. Hidraulics. Divis. ASCE 109(12):1603-1621.

Chow VT, Maidment DR, Mays LW (1998). Hidrología aplicada. Santafé de Bogotá, Colombia. Editorial McGraw Hill, P. 584.

Crockford RH, Richardson DP (2000). Partitioning of rainfall into throughfall, stemflow and interception: effect of forest type, ground cover and climate. Hydrol. Proc. 14:2903-2920.

García-Estrínaga P, Blazquez A, Alegre J (2006). Determinación de la interceptación y la redistribución del agua de lluvia a su paso a través de vegetación arbustiva en traslocación y escorrentía cortical: Una modificación de método Interception Flor Collection Box. Instituto Madrileño de Investigación y Desarrollo Rural Agrario y Alimentario. I.M.I.D.R.A, P. 6.

Gash JHC (1979). An analytical model of rainfall interception by forests. Quarterly J. Royal. Meteorol. Soc. 105:43-55.

Gerrits AMJ, Savenije HHG, Hoffmann L, Pfister L (2006). Measuring forest floor interception in a beech forest in Luxenbourg. Hydrol. Earth Syst. Sci. Dis. 3:2323-2341.

Groen MM, Savenije HH (2006). A monthly interception equation based on the statistical characteristics of daily rainfall. Water Resour. 42:1-10.

Hashino M, Yao H, Tamura T (2010). Micro-Droplet Flux in Forest and its Contribution to Interception Loss of Rainfall – Theoretical Study and Field Experiment. J. Water Resour. Protect. 2:872-879.

Horton RE (1919). Rainfall interception. Monthly Weather Rev. 47:603–623.

Jackson NA (2000). Measured and modelled rainfall interception loss from an agroforestry system in Kenya. Agric. Forest Meteorol. 100:323-336.

Jong SM, Jetten VG (2007). Estimating spatial patterns of rainfall interception from remotely sensed vegetation indices and spectral mixture analysis. Int. J. Geogr. Inform. Sci. 21:529-545.

Keim RF, Skaugset AE, Link TE, Iroume A (2004). A stochastic model of throughfall for extreme events. Hydrol. Earth Syst. Sci. 8:23-34.

Loescher HW, Power JS, Oberbauer SF (2002). Spatial variation of through fall volume in an old-growth tropical wet forest. J. Trop. Ecol. 18:397-407.

Love D, Uhlenbrook S, Corzo-Perez G, Twomlow S, Van der Zaag P (2010). Rainfall–interception–evaporation–runoff relationships in a semi-arid catchment, northern Limpopo basin, Zimbabwe. Hydrological Sci. J. 55(5):687-703.

Li X, Shi P, Liu L, Gao S, Wang X, Cheng L (2005). Influence of pebble size and cover on rainfall interception by gravel mulch. J. Hydrol. 312:70-78.

Mastachi-Loza C (2007). Intercepción de precipitación en dos especies de ambiente semidesértico: *Acacia farnesiana* y *Prosopis laevigata*. Tesis de maestría. Universidad Autónoma de Querétaro, P. 108.

Mao J, Pitman AJ, Phipps S, Abramowitz G, Wang Y (2011). Global and regional coupled climate sensitivity to the parameterization of rainfall interception. Clim Dyn. 37:171–186.

Moraes RF, Krajewski WF (2013). Rainfall interception by maize canopy: Development and application of a process-based model. J. Hydrol. 489:246–255.

Mulder JPM (1985). Simulating interception loss using standard meteorological data. *The* forest Atmosphere Interation. Reidel, Dordrecht, pp. 177-196.

Muzylo A, Llorens P, Valente F, Keizer JJ, Domingo F, Gash JHC (2009). A review of rainfall interception modelling. J. Hydrol. 370:191-206.

Onozawa Y, Chiwa M, Komatsu H, Otsuki K (2009). Rainfall interception in a moso bamboo (Phyllostachys pubescens) forest. J. For. Res. 14:111-116.

Raat KJ, Draaijers GPJ, Schaap MG, Tietema AD, Verstraten JM (2002). Spatial variability of through all water and chemistry and forest floor water content in a Douglas fir forest stand. Hydrol. Earth Syst. Sci. 6:363-374.

Reid L, Lewis J (2009). Rates, timing, and mechanisms of rainfall interception loss in a coastal redwood forest. J. Hydrol. 375:459-470.

Rodrigo A, Ávila A (2001). Influence of simple size in the estimation of mean through fall in two Mediterranean holm oak forest. J. Hydrol. 243:216-227.

Rutter AJ, Kershaw KA, Robins PC, Morton AJ (1971). A predictive rainfall interception in forest: derivation of the model from observations in plantation of Corsican pines. Agric. Meteorol. 9:367-384.

Savenije HG (2004). The importance of interception and why we should delete the term evapotraspiration from our vocabulary. Hydrol. Proc. 18:1507-1511.

Schellekens J, Bruijnzeel LA, Scaten AFN, Bink NJ, Holwerda F (2000). Evaporation from a tropical rain forest, Luquillo Experimental Forest, eastern Puerto Rico. Water Resour. Res. 36(8):2183-2196.

Schowalter TD (1999). Throughfall volume and chemistry as affected by precipitation volume, sampling size, and defoliation intensity. Great Basin Nat. 59:79-84.

Serrano-Muela MP, Lana-Renault N, Nadal-Romero E, Regues D. Marti-Bono C, Garcia-Ruiz J (2008). Forests and Their Hydrological Effects in Mediterranean Mountains. Mountain Res. Develop. 28:279-285.

Steidle AJ, Ribeiro A, Carvalho D, Bahia O, Goncalves W, Oliveira M (2011). Simulation of Rainfall Interception of Canopy and Litter in Eucalyptus Plantation in Tropical Climate. Forest Sci. 58(1):54-60.

Tucci CEM (2001). Precipitação In Hidrologia: *ciência e aplicação. 2.ed. Porto Alegre*: Universidade Federal do Rio Grande do Sul, pp. 177-242.

Van J, Jarvis MT, Levia DF, Friesen J (2011). Instrumental method for reducing error in compression-derived measurements of rainfall interception for individual trees. Hydrol. Sci. J. 56(6):1061-1066.

Villón Béjar M (2006). Hidrología Estadística. Editorial Tecnológica de Costa Rica, P. 440.

Wang L, Zhang Q, Shao M, Wang Q (2013). Rainfall Interception in a Robinia pseudoacacia Forest Stand: Estimates Using Gash's Analytical Model. J. Hydr. Eng. 18(4):474-479.

Wani MA, Manhas RK (2012). Rainfall interception in relation to the tree architecture of Pinus wallichiana. Curr. Sci. 103(7):821-827.

Xiao Q, McPherson G (2011). Rainfall interception of three trees in Oakland, California. Urban Ecosyst. 14:755-769.