Helmut Elsenbeer, Keith Cassel, L. Zuñiga

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THROUGHFALL IN THE TERRA FIRME FOREST OF WESTERN AMAZONIA

H. Elsenbeer[1], D.K. Cassel[2] and L. Zuniga[3]

[1]*Institute of Geography, University of Berne, Hallerstr. 12, 3012 Berne (Switzerland)*

[2]*Department of Soil Science, North Carolina State University, Raleigh, NC 27695-7619 (U.S.A.)*

[3]*Proyecto Suelos Tropicales, Apartado 248, Lima 100 (Peru)*

ABSTRACT

Throughfall measurements were made under primary terra firme rainforest in the Rio Pichis valley, in the Upper Amazon Basin of Peru. Based on 214 precipitation events over nearly 18 months, throughfall was estimated to be 83.1±8.8% of gross precipitation. Regression analysis of all events revealed that gross precipitation is the only significant explanatory variable; the use of one-burst events does not significantly improve the regression relationship. Gross precipitation is, however, a poor predictor of throughfall for small rainfall events. The two forest structure parameters, canopy capacity, S, and free throughfall coefficient, p, were determined to be 1.3±0.2 mm and 0.32±0.18 mm. Rainfall intensity was found to influence these parameters. New methods which attempt to minimize the influence of meteorologic variables are used to estimate the potential values of these canopy parameters.

INTRODUCTION

The vegetation canopies of the Earth's surface act as temporary stores for a portion of the rainfall they receive. This storage capacity has received considerable attention in the humid tropics in the context of regional water recycling. Salati and Vose (1983, 1984), Salati and Marquez (1984) and Salati (1987) stressed the role of water recycling and its control by the rainforest in the Amazon Basin, claiming that as much as 75% of precipitation is returned to the atmosphere by evapotranspiration. Studies by Franken et al. (1982) and Franken and Leopoldo (1984) indicate that about one-third of this amount is derived from interception storage. Forest conversion could diminish this store, interrupting the regional recycling process, and negatively affecting the regional water balance, especially in the western part of the Basin. Lockwood and Sellers (1982) modeled possible changes in interception storage resulting from deforestation. In a modeling study of tropical deforestation, Dickinson and Henderson-Sellers (1988) emphasized the role of canopy hydrology in land surface parametrizations of general circulation models.

Earlier literature on interception in the humid tropics is reviewed by Clarke (1987). The only recent interception study in the Amazon Basin was done by Lloyd and Marques (1988) near Manaus in Central Amazonia. Tropical rainforests may influence the regional, and possibly global climate, but the present knowledge about throughfall and interception in these ecosystems is still fragmentary. To put the frequently-cited results from Central Amazonia into perspective, we provide additional data from the western portion of the Amazon Basin.

The objectives of this study were:

(1) to estimate throughfall on a storm-event basis,
(2) to evaluate the influence of rainfall variables on throughfall, and
(3) to determine two forest structure parameters - canopy capacity and free throughfall coefficient.

SITE DESCRIPTION AND INSTRUMENTATION

Physiography

The study site La Cuenca, a first-order catchment of about 0.75 ha, is located in the Rio Pichis valley in the Selva Central of Peru at 74°5'W, 10°13'S (Fig.1). The Pichis is a headwater river of the Rio Pachitea, which is a tributary to the Rio Ucayali, one of the three source rivers of the Amazon in Peru. The catchment is situated on a dissected former peneplain, at about 300 m a.m.s.l. The local relief is about 30 to 40 m with short, steep slopes up to 40° .

Climate

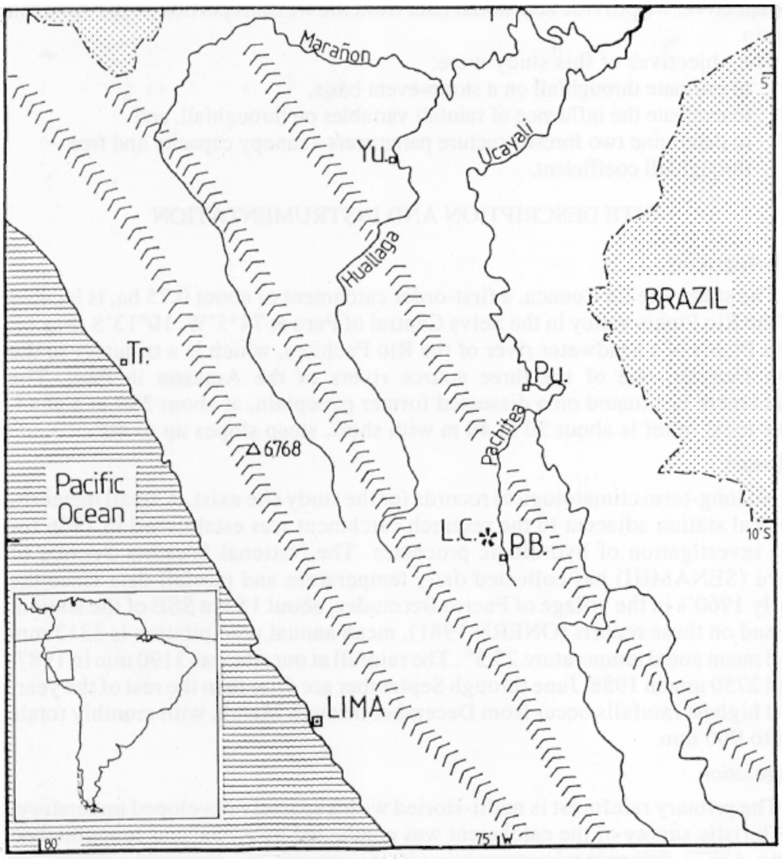
No long-term climatological records for the study site exist. A small meteorological station adjacent to the research catchment was established in 1986 for the investigation of hydrologic processes. The National Weather Service of Peru (SENAMHI) has collected daily temperature and rainfall data since the early 1960's in the village of Puerto Bermudez, about 15 km SSE of the station. Based on these reports (ONERN 1981), mean annual precipitation is 3313 mm and mean anual temperature 25.5° . The rainfall at our site was 3190 mm in 1987, and 2750 mm in 1988. June through September are drier than the rest of the year, and highest rainfalls occur from December through March, with monthly totals up to 900 mm.

Vegetation

The primary rainforest is multi-storied with a sparsely developed understory. A floristic survey of the catchment was conducted by A. Salazar (unpublished data, 1987), following Lamprecht's (1964) procedures. Excluding the valley floor, 135 trees with a diameter at breast height (dbh) larger than 25 cm were counted. They belong to 57 species in 25 families. The most common family in terms of number of species and individual trees is Moraceae, with 7 species and 31 trees in the surveyed size class. Sapotaceae account for 5 species and 15 trees, and Euphorbiaceae for 3 species and 9 trees. Of the 135 trees with dbh>25 cm, 30 were taller than 30 m, 72 were 25 to 30 m tall, 31 were 20 to 25 m tall, and two were under 20 m. The number of trees in the size class 5<dbh<25 cm was estimated to be 800; for dbh<5 cm, 21000.

Instrumentation

Gross rainfall was measured with a tipping-bucket raingage (340 cm^2 orifice) connected to an event recorder. The raingage was situated in the centre of a 2-ha clearing, about 200 m from the research catchment; the clearing was large enough to assure a 45° angle between the raingage and the tallest trees (ca. 25 m) at the fringe of the forest. In the forested catchment, 8 sheet metal troughs, 1.8x0.1x0.1 m, were installed 1.5 m above the ground along a sideslope from the creek draining the catchment to an interfluve, covering a length of about 30 m.



* L.C.: La Cuenca Research Station;
P.B.: Puerto Bermudez; Pu.: Pucallpa; Tr.: Trujillo; Yu.: Yurimaguas

FIG. 1—The location of the research catchment La Cuenca in Peru

A fixed trough system was considered preferable to the roving-gage system advocated by Wilm (1943) and Lloyd and Marques (1988). One trough was installed in the clearing. The interception troughs had spouts to drain the collected water into 19-liter containers through a funnel. The total intercepting area, consisting of trough, spout, and funnel, was determined for each trough to the nearest 10cm². Throughfall volume was determined to the nearest 10 ml no earlier than 1 hour after gross precipitation had ceased. Measurements began in mid-December 1986; the data set used in the present analysis comprises all observations through May 1988. The total intercepting area of all eight troughs corresponds to that of 82 200cm²-orifice gages, of 130 gages used by Lloyd and Marques (1988), or of 164 gages used by Franken et al. (1982).

Data Analysis

The following information for each rainfall event was extracted from the daily rainfall charts: magnitude of gross precipitation (Pg); duration; length of antecedent dry period; magnitude of previous rainfall event; maximum 60-minute, 30-minute, 20-minute, 15-minute, 10-minute, and 5-minute intensities (denoted as I_{60}max, I_{30}max, I_{20}max, I_{15}max, I_{10}max; and I_5max, respectively); and the average intensity, R.

Due to the short period of monitoring precipitation, several operational definitions were used for this study. An event (or a burst, see below) was rainfall of a magnitude of 0.2 mm or larger and I_{10}max of 1.2 mm/h or greater; these constraints excluded occasional drizzles. An event consisted of two or more bursts if no precipitation was registered for 1 h or more but less than 6 h. If more than 6 h elapsed between two bursts, the throughfall measurement was considered to be two events, rather than to consist of two bursts. This allows separate analysis of 'multi-burst' or composite events, during which presumably more evaporation from the canopy occurs than during 'one-burst' events. The length of a burst, which in most cases is equivalent to the event duration, was determined by the last tick-mark on the chart which is separated from the previous one by less than 1 h, and estimated to the nearest 10 min. This procedure accommodates those events that slowly decreased in intensity, but excluded occasional drizzles in the wake of large events, which would have inflated the duration estimate, resulting in a very low average intensity. In the case of several bursts, the event duration was taken as the sum of the burst durations if the event occurred at night; evaporation between bursts was assumed to be negligeable as the Piche evaporimeter readings did not change during the night. Daytime events or bursts were excluded from the analysis if their I_{10}max was lower than 2.5 mm/h and if the Piche evaporimeter in the clearing indicated evaporative conditions. This is pertinent only when such an event or burst was not evaluated but preceded an event that was measured; in determining the latter's antecedent dry period and magnitude of previous event, excluding such cases implies that the rainfall encountered an unsaturated canopy. The term "event", therefore," is used in an operational context only.

The throughfall measured in each of the 8 troughs was expressed as a fraction of the gross precipitation collected in an identical trough located in the clearing. This fraction was then multiplied by the gross precipitation measured with the tipping-bucket raingage to arrive at throughfall for each trough. For further data analysis, arithmetic means of the eight hillslope troughs were used.

A significance level of 0.05 was used for all statistical tests.

Estimation of canopy capacity S

Our approach is conceptually similar to that of Bringfelt and Hårsmar (1974). Data for one-burst events were divided into two groups, one with Pg<Pg' and one with Pg>Pg', where Pg' is the rainfall necessary to fill the canopy capacity. Regression analyses were performed with Pg as the only explanatory variable, for several assumed values of Pg'; possible Pg' range from 0.9 to 4.1 mm (see, for example, Jackson, 1975; Saxena, 1986; Gash and Morton, 1978; Pearce and Rowe, 1981). While the regression coefficient of the respective larger subset for a given Pg' was barely affected by the choice of Pg', that of the respective smaller subset changed considerably. Starting with a Pg' value of 1 mm and increments of 0.5 mm, the regression coefficient first decreased with increasing Pg' and then increased to approach that of the overall regression. To determine S, we chose the assumed Pg' value that resulted in the smallest slope for the domain Pg<Pg' as the rainfall necessary to saturate the canopy. The procedure is illustrated in Table 6 and shows that the smallest slope, 0.47 mm, is associated with a Pg' value of 2.0 mm, with an assumed uncertainty of 0.2 mm.

A second method, conceptually similar to that of Leyton et al. (1967), was employed to derive S. Only one-burst events of 50 min or shorter, an antecedent dry period of 8 h or longer, and Pg<Pg' were used to regress throughfall on Pg. In contrast to Leyton et al. (1967), the intercept of the regression line itself, and not that of the envelope to all data points, was interpreted as S.

TABLE 1—La Cuenca research catchment — Summary of descriptive statistics of rainfall variables

Variable	Units	Events	Median	Max.	Min.
Magnitude	mm	214	8.7	70.3	0.3
I_{60}max	mm/h	170	6.7	50.0	0.5
I_{30}max	mm/h	198	9.1	66.0	0.4
I_{15}max	mm/h	211	12.4	76.0	0.8
I_{5}max	mm/h	214	19.2	96.0	1.2
R	mm/h	214	3.2	31.1	0.4
Duration	min	214	170	960	10

RESULTS AND DISCUSSION

Rainfall characteristics

A total of 214 rainfall events were evaluated. The descriptive statistics of selected rainfall variables are summarized in Table 1. Total rainfall during the 18-month-long period was 4812 mm. Due to the limited capacity of the containers, six events larger than 70.3 mm could not be sampled. The largest rainfall event was a single-burst of 120.7 mm. The 214 evaluated events covered the complete range of recorded rainfall intensities and are thus representative of all the events that occurred during the study period. Whether they are a representative sample of the region cannot be determined, as little precipitation data is available for the western Amazon Basin.

The median of average rainfall intensity, R, is low compared to short-term maximum intensities, reflecting the high variability of rainfall intensity within events. This is also true for one-burst events. High short-term intensities do not necessarily imply high average intensities. Many, if not all, rainfalls with high short-term intensities also have long durations, and thus low average intensities. Short one-burst events that end abruptly have high average intensities, and are typically associated with isolated airmass thunderstorms. The larger events consisted of both cumuliform (high-intensity phase) and stratiform (low-intensity phase) precipitation. These larger events frequently occurred in clusters or consisted of several bursts, and are probably associated with mesoscale convective complexes or so-called cloud clusters (e.g. Houze, 1982). Their convective cells may give rise to individual high-intensity bursts, while low-intensity precipitation between bursts may stem from stratiform clouds associated with those cells.

TABLE 2—Gross precipitation (Pg), throughfall, and interception, differentiated according to event type at La Cuenca research catchment.

	Pg	Throughfall	Interception
All events			
Amount (mm)	2987	2483	505
% of Pg	(n=214)	83.1	16.9
One-burst events			
Amount (mm)	2130	1781	350
% of Pg	(n=167)	83.6	16.4
Composite events			
Amount (mm)	857	702	155
% of Pg	(n=37)	81.9	18.1

Total throughfall and interception

Table 2 summarises gross precipitation, throughfall and interception differentiated according to event type. The slightly lower value for composite events might reflect evaporative losses which increase with increasing event duration; a lysimeter-based interception study revealed that such losses may be as high as 0.8 mm/h (Dunin et al., 1988).

Raich (1983) lists throughfall values for a wide variety of tropical forests, ranging from 46 to 97% of total rainfall. This range may reflect meteorologic and vegetation differences of the study sites, or differences in methodology. Some results cited by Raich are based on data that appear inadequate in view of the high spatial and temporal variability of throughfall, being based on a small number of collectors and/or a short time record.

Throughfall data from a wide range of ecosystems are presented in Table 3. With the exception of subtropical northern India, throughfall is highest in lower latitudes, and is comparable to values at our site and in Central Amazonia. Sites from Raich's (1983) list described as 'tropical wet', 'rain', 'evergreen rain', or 'tropical moist', all of which might be applied to the forests of lowland Central Peru, range from 77 to 90% throughfall. Throughfall for lower latitudes (Table 3) fall within this range. The percentage cited by Manokaran (1979) is probably an underestimate, because he did not allow percentages for individual events to exceed 100. The funnelling effect of the canopy ('drip points') may result in throughfall percentages exceeding 100, as well as cloud and mist capture, as reported by Pook et al. (199lb). Also, catch by the measuring device may be influenced by its position - underneath the canopy or in the open - thus resulting in an inherent error. We concur with Hutjes et al. (1990) that throughfall percentages larger than 100 should not be disregarded, unless instrumental bias can be demonstrated.

The comparison of throughfall from different ecological or climatological zones is difficult if the error associated with a reported value is such that its confidence interval includes values from distinctly different sites. This is illustrated by results from the two Barro Branco sites in Brazil (Table 3) which had similar vegetation but employed different experimental arrangements. Lloyd and Marques (1988) cited a 2% error for their mean throughfall value of 91%, and estimate an error of about 12% for the value reported by Franken and Leopoldo (1984). At the 95% level, the difference between the two reported values is not significant. This brings into question the validity of some previously published results and emphasizes the need for a standardized experimental arrangement. As the values of Table 3 would have to be increased by about 1-2% to yield 'net' precipitation (to account for stemflow), an interception estimate of about 25% for the Amazon rainforest appears too high. This value is frequently cited by those emphasizing the role of forests in regional water cycling, e.g. by Salati and Vose (1984), Salati and Marquez (1984) and Salati (1987). Since no throughfall value from the humid tropics was derived with greater precision than that of Lloyd and Marques (1988), the error margins associated with most reported values certainly accommodate a variety of interpretations of the role of forests in regional water recycling.

Regression equations

As physically-based predictive models require substantial data input, simple relationships between gross rainfall and throughfall, or interception, are likely to be a widely used predictive tool. The few weather stations in Western Amazonia record only daily rainfall; recording raingages are usually operated only by international research programs. Thus, information on rainfall variables that affect the interception process, e.g., intensity or length of antecedent dry period, is not available. Knowledge of rainfall variables other than magnitude, however, may not be necessary for predicting throughfall.

The results from the regression of throughfall (T) on gross precipitation (Pg) are summarized in Table 4. Table 5 shows results when both variables undergo log-transformation before regression. The latter is based on the finding that the frequency distributions of Pg and T approach a log-normal distribution. Regressions were performed for all events, then one-burst and composite events.

The use of log-transformed variables did not improve the coefficient of determination, R^2, but resulted in a larger standard error of the regression coefficient and a considerably smaller standard error of the intercept (Tables 4 and 5). A semilogarithmic regression with only the explanatory variable transformed yielded much lower R^2 values.

The slope of the composite-event equation was significantly different from the one-burst and the all-event equations. The smaller slope for the composite-event equation was expected because composite events were invariably longer, resulting in more evaporation from the canopy. The intercept estimates for the event types are not significantly different. The parameter estimates for the one-burst case are not different from those for all events; this suggests that

TABLE 3—Throughfall percentages from selected non-coniferous forest ecosystems

Location	Latitude	Forest Type	Throughfall	Reference
Himalaya India	29° 24'N	mixed oak	80.8-84.7	Pathak et al. (1985)
Malaysia	02° 05'N	dipterocarp	77.6	Manokaran (1979)
Usambara Tansania	04° 51'S	submontane rain forest	78.0	Lundgren and Lundgren (1979)
Central Amazonia Brazil	02° 57'S	terra firme rain forest	81.0	Franken and Leopoldo (1984)
Central Amazonia Brasil	02° 57'S	terra firme rain forest	91.0	Lloyd and Marques (1988)
Western Amazonia Peru	10° 13'S	terra firme rain forest	83.1	this study
New Zealand	42° 05'S	beech-podocarp	73.0	Rowe (1979)
New Zealand	41° 48'S	evergreen beech	69	Rowe (1983)
France	48° 44'N	mixed beech	74.0	Aussenac (1968)*
Germany	50° 41'N	beech-oak	67.0	Balazs (1983)**
Tai forest Ivory Coast	05° 51'N	evergreen	90.8	Hutjes et al. (1990)
French Guyana	05° 20'N	rain forest	92.8	Ducrey and Guehl (1990)
Andes Colombia	04 50'N	montane rain	81.7-87.6	Veneklaas and van Ek (1990)

* calculated from monthly totals May through September
** summer only

throughfall may be predicted from daily gross rainfall readings. A rain day in this environment is likely to encompass a multiple-burst event or even several events. The first relationship from Table 4,

$$T = -0.80(\pm 0.32) + 0.89(\pm 0.02)Pg \qquad (1)$$

is adequate where total daily rainfall is the only information available.

The low importance of rainfall variables other than magnitude is not surprising in an environment where rainfall intensities are high, and as long as events of all magnitudes are combined as for Eq. (1). Where intensity was shown to be important, e.g. in the case of Bultot et al. (1972), the storms were of generally "low" intensities. The average intensity of 160 storms was 1.5 mm/h; no data on maximum intensities were given. Although they did not treat storm duration as an explanatory variable, they suggest that the lower interception during 'high-intensity' events was due to less evaporation from the canopy. This result stems from the short duration of such events. Rutter et al. (1971) presented the mean intensities of the four storms used in the development of their model; the highest value was 3.9 mm/h, which is lower than the highest value cited by Bultot et al. (1972). Rutter et al. (1971) concluded with Bultot et al. (1972) that interception was inversely related to intensity. Further evidence for the influence of rainfall characteristics on interception is provided by Pook et al. (199la). In all three cases the response variable was interception, rather than throughfall. Inferences about the relationship between a rainfall variable and interception based on the relationship between the same variable and throughfall, and vice versa, may not be valid. Thus, Jackson's (1975) result that interception increases with rainfall intensity, does not necessarily contradict our results that rainfall intensity is not a significant predictor of throughfall. Rainfall intensity assumes importance, however, under conditions similar to those of Rutter et al. (1971) and Bultot et al. (1972).

TABLE 4—Regression equations with gross rainfall as the independent variable and throughfall as the dependent variable. Standard errors are shown in parentheses.

Event type	Intercept	Slope	R^2
all	-0.801 (0.163)	0.888 (0.008)	0.983
one burst	-0.803 (0.156)	0.899 (0.008)	0.987
composite	-0.759 (0.538)	0.861 (0.023)	0.968

Forest structure parameters

Canopy capacity

If S were strictly a vegetation parameter, it could be calculated directly from the regression parameters given for Pg' (Table 6). The low coefficients of determination in these size classes, compared to those presented in Table 4, suggests that other variables might be important. Hence, a multiple regression analysis was performed for the same size classes as in Table 6, with the additional explanatory variables duration, length of antecendent dry period, magnitude of previous event, I_{10}max, I_5max, R, the respective squared terms, the log-transformed terms, as well as kinetic energy terms for the three respective intensity terms (KE_{10}, KE_5, and KE_{av}). The relationship given by Wischmeier and Smith (1958) was used to calculate the kinetic energy for the maximum short-term intensities. The kinetic energy of a raindrop arriving at a leaf may determine whether it is held there by surface forces or just bounces off.

Table 7 lists all significant variables for some of the size classes given in Table 6. The additional constraint of an antecendent dry period of 8 h or longer was imposed.

Gross rainfall, untransformed, becomes a good predictor only after canopy storage is filled, i.e. for events larger than Pg'. The influence of other rainfall variables was most pronounced at smaller Pg' values in the case of eucalypt (Pook et al., l991a). The significant squared term for Pg'=2.5 mm may indicate the curvature in this region around the inflection point. Short-term maximum rainfall intensities are as important for interception as gross rainfall, as long as the threshold value of Pg' is not exceeded. only those events with Pg<Pg' that have low maximum short-term intensities should be used to determine S. In regions where high intensities are common, failure to restrict the data in this manner may result in an underestimation of S.

TABLE 5—Regression equations with log-transformed gross rainfall as the independent variable and log-transformed throughfall as the dependent variable. Standard errors are shown in parentheses.

Event type	Intercept	Slope	R^2
all	-0.388 (0.018)	1.240 (0.018)	0.959
one burst	-0.406 (0.020)	1.26 (0.021)	0.958
composite	-0.246 (0.036)	1.117 (0.030)	0.968

TABLE 6—Parameters for the regression of throughfall (T) on gross precipitation (Pg), with Pg<Pg', for several assumed values of Pg'. Only one-burst events were selected.

Pg' (mm)	Intercept	Slope	R^2
1.0	-0.25	0.76	0.43
1.5	-0.08	0.56	0.42
2.0	-0.02	0.47	0.38
2.5	-0.21	0.71	0.25
3.0	-0.04	0.55	0.24
3.5	-0.07	0.58	0.32
4.0	-0.11	0.61	0.46

Canopy capacity, S, is given by

$$S=Pg'-T \tag{2}$$

where T is the amount of throughfall occurring when gross precipitation equals Pg'; it is derived from a regression of T on Pg for events smaller than Pg'. The regression based on rainfalls for which the antecedent dry period is longer than 8 h is:

$$T=0.39Pg \tag{3}$$

For Pg=Pg'=2.0 mm, equations (3) and (2) yield T=0.7 mm and S=1.3 mm. The regression equation based on rainfalls with I_5max < 8 mm/h is :

$$T=0.33Pg \tag{4}$$

For Pg=Pg'=2.0 mm this yields T=0.6 mm and S=1.4 mm.

Taking into account that Pg' was estimated as 2±0.2 mm, as well as the error in the regression coefficients, the best estimate for S is 1.3±0.2 mm.

Bultot et al. (1972) introduced the concept of potential and actual interception; we suggest a similar distinction between potential and actual canopy capacity. The former is a true vegetation parameter, whereas the latter is influenced by meteorologic conditions, mainly by rainfall intensity. This distinction is of practical consequence for the determination of S, which was always taken to reflect only vegetation characteristics, i.e. the potential canopy capacity. The only events to be considered are those of short duration, modest rainfall intensity, and unaccompanied by wind. The requirement of a dry canopy, met by a minimum defined antecedent dry period, does not always seem sufficient. Whenever S values are compared, with the assumption that different S values reflect differences in canopy characteristics, these S values must be potential S values as defined above. The influence of meteorologic conditions, especially rainfall intensity, on canopy capacity, was pointed out by Rowe (1983) and Singh (1977).

The second method employed to derive S yielded a canopy capacity of 1.2 mm. While this compares favorably with the above estimate of 1.3 mm, the precision of the second method is very low and the method is not recommended unless a large data set is available.

These canopy capacity values are compared with published values for non-coniferous forests in Table 8. They fall well within the range presented by the other forest types, i.e. tropical rainforest canopies apparently do not store more water than high-latitude forests. Herwitz (1985), however, emphasized the role of woody parts in interception storage, especially in the high-intensity events. Further investigations may allow revision of the canopy capacity concept to include woody parts. The method for determining S appears to greatly affect the value, as is evident from Rowe's (1983) results for evergreen beech. The method selected should take into account the prevailing meteorologic conditions.

TABLE 7—Significant variables for the prediction of throughfall for small one-burst events, and the corresponding coefficients of determination. All events were preceded by a dry period of at least 8 hours.

Pg'	Variables	R^2
1.0	Pg^2	0.45
1.5	I_5^2	0.61
2.0	KE_5	0.35
2.5	Pg^2	0.66
3.0	Pg, I_5^2	0.61, 0.06

Variables: Pg: gross precipitation
I_5: max. 5-min rainfall intensity
KE_5: kinetic energy based on I_5

TABLE 8—Canopy capacity (S) values from selected non-coniferous forest ecosystems.

Forest type	S (mm)	Reference
Mixed hardwood	1.9±0.5	Aussenac (1968)
Submontane rainforest	0.9	Jackson (1975)
Evergreen beech	0.5-0.7	Rowe (1983)*
	1.2-1.5	Rowe (1983)**
Hardwood	0.03-1.6	Helvey and Patrick (1965)#
Acacia plantation	0.5-0.6	Bruijnzeel and Wiersumm (1987)
Terra firme rainforest	1.3±0.2	this study
Eucalyptus	0.35	Dunin et al. (1988)
Rainforest	0.6	Hutjes et al. (1990)

* Method Leyton et al. (1967)
** Method Gash and Morton (1978)
\# representing all eastern U.S. hardwoods

Free throughfall coefficient

The free throughfall coefficient p is defined as that fraction of gross rainfall that reaches the ground without hitting the canopy. It can be derived from a regression of throughfall on gross precipitation for events with $Pg<Pg'$; as soon as the canopy capacity is filled, throughfall consists of free throughfall and canopy drip. The considerations that applied to the determination of S apply here as well. Thus, the regression equation (4) is used. Theoretically, there should be no intercept, according to

$$T=pPg \tag{5}$$

Very small events may not be registered due to wetting losses in the troughs. The regression coefficient, representing p, is 0.32±0.18 mm. Jackson (1975) found a p value of 0.25, Bruijnzeel and Wiersum (1987) a value of 0.43±0.18 mm and 0.38±0.17 mm for two sampling periods, and Rowe (1983) reported no free throughfall.

CONCLUSIONS

The terra firme forest allowed 83.1±8.8% of gross precipitation to pass as throughfall. This result agrees well with values measured elsewhere in the humid tropics, given the considerable error associated with such measurements. The forest parameters fall within the range of values reported for broad-leaf forests throughout all latitudes. These parameters should be determined under well-defined meteorological conditions. The actual canopy capacity is influenced by meteorologic conditions, whereas the potential canopy capacity is determined by canopy characteristics. Hence, rainfall variables other than magnitude influence interception for events that do not saturate the canopy, but are of no consequence for larger events. Grouping one-burst and multiple-burst events does not affect significantly the regression equation describing throughfall as a function of gross precipitation. Daily rainfall readings are thus probably sufficient to estimate throughfall on a monthly or annual basis.

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FORTHCOMING EVENTS

21-25 November 1994: Water Down Under 94, combining the 25th Congress of the International Association of Hydrogeologists with the International Hydrology and Water Resources Symposium of the Institution of Engineers, Australia; Adelaide, South Australia. Contact: AE Conventions, 11 National Circuit, Barton 2600, ACT, Australia (Phone: 0061-6-270 6520, Fax: 0061-6-273 2918).

2-5 April 1995: The Fifth Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst; Gatlinburg, Tennessee. Contact: B.F.Beck, P.E. LaMoreaux and Assoc., Inc., P.O. Box 4412, Oak Ridge, TN, USA, 37831-4412. (Phone: 001 615 483 7483).

23-26 April 1995: IMAM'95: Seventh Congress, International Maritime Association of Mediterranean; Dubrovnik, Croatia. Contact: IMAM'95 Congress Secretariat, Brodarski institut, Av. V. Holjevca 20, Zagreb 41020, Croatia. (Phone: 00385 41 65 10 22; Fax: 00385 41 65 01 30; Email: imam@hrbi.hr).

20-23 August 1995: Third International Symposium on Hydrological Applications of Weather Radars; São Paulo, Brazil. Contact: III International Symposium on Hydrological Applications of Weather Radars, Av. Brigadeiro Luiz Antônio, 317 CJ 33, 01317-901, São Paulo, Brazil. (In New Zealand, contact G.L. Austin, Physics Dept, University of Auckland, Auckland.)

25-28 June 1995: AWRA (American Water Resources Association) 1995 Summer Symposium, Water Resources and Environmental Hazards: Emphasis on Hydrologic and Cultural Insight in the Pacific Rim; Honolulu, Oahu, Hawaii. Contact: Michael C. Fink, Director of Meetings, American Water Resources Association, 5410 Grosvenor Lane, Suite 220, Bethesda, Maryland, USA, 20814-2192. (Phone: 001 301 493 8600; Fax:001301 493 5844).

16-20 October 1995: FISOLS 95, Fifth International Symposium on Land Subsidence; The Hague, Netherlands. Contact: Secretariat FISOLS 95, Mr F.H. Schröder, c/o Netherlands Geodetic Commission, P.O. Box 5030, NL-2600 GA Delft, The Netherlands. (Phone: 0031 15 782819; Fax: 0031 15 782745; Email: shroder@tudgv1.tudelft.n).

5-9 November 1995: American Water Resources Association 31st Annual Conference - Symposium on Water Management in Urban Areas, Symposium on Advances in Development and Use of Models in Water Resources, Symposium on North American Water Resources - Houston, Texas (reconvened conference, 10-12 November 1995, Cancun, Mexico). Contact: Michael C. Fink, Director of Meetings, American Water Resources Association, 5410 Grosvenor Lane, Suite 220, Bethesda, Maryland, USA, 20814-2192. (Phone: 001 301 493 8600; Fax: 001 301 493 5844).

4-14 August 1996: 30th International Geological Congress; Beijing, China. Contact: Secretariat Bureau, 30th International Geological Congress, P.O. Box 823, Beijing100037, P.R. China.