Interception

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Introduction

To hydrologists who focus on the terrestrial part of the hydrological cycle, precipitation is generally seen as the starting point of the water cycle. Although one could start with any other point in the cycle as well: e.g. advection of moisture to the land or evaporation from the oceans, it is common to begin the terrestrial water cycle with the rainfall, probably because rainfall is more easily measurable then other incoming fluxes. This cycle involves many interconnected processes (fluxes), separation points, feedback loops, and stocks where the water resides over longer or shorter periods of time. Starting from the rainfall, the first process that comes into view is interception. It retains the water before it can continue its path in the water cycle and it allows for a direct feedback loop to the atmosphere. Depending on the precise definition of this process, interception can be understood to mean different things.

First of all it is important to decide whether we consider interception as a stock or a flux, or as the combination of both. If we consider it a stock, then it is the amount of rainfall that can be temporarily stored on the land (with its natural and man-made cover) to be evaporated shortly after (or during) the rainfall event. Here, we actually mean the interception capacity. If we consider interception as a flux, then it is the evaporation from intercepted water, which we express in mm per unit of time. If we consider interception as an integrated process, then it is the sum of the rate of change of intercepted water and its evaporation:

$$I = \frac{\mathrm{d}S_I}{\mathrm{d}t} + E_I \qquad (1)$$

where I is the interception process (mm/d), S_I is the interception storage (mm), and E_I is the evaporation from interception (mm/d). The interception I is the part of the rainfall which is intercepted and, after a short period of time, turns into the evaporative flux E_I. For a time scale in the order of 1 day, it is safe to assume that $I= E_I$.

Next, it is important to define the location of the interception process in the hydrological cycle. The most logical place is between the atmosphere and the first separation point where the rainfall splits into interception, surface runoff and infiltration (see Figure 1). The interception stock (S_I) is located at the first separation point. In this definition the interception process includes evaporation from wet leaves, wet land cover (included man-made structures and roads), wet mulch, wet forest floor and even wet soil. In short, it is the fast evaporation mechanism that dries moist land cover during and directly after the rain.

A more narrow definition of interception, often used, is the difference between rainfall and “throughfall”, the rain that falls through the leaves of e.g. a tree. In this definition, interception is merely the amount of water retained by the leaves of a tree. This is not a very workable definition for hydrologists since it leaves evaporation from land surface not catered for. Hydrologists who do use this definition, however, combine wet surface evaporation with all other evaporative fluxes and call it evapotranspiration, which is not really a process, but rather a combination of different evaporation processes with different time scales and characteristics (Savenije 2004).

The total evaporation E in a catchment is the sum of a number of different processes: interception I, transpiration T, surface evaporation E_s, and open water evaporation E_o (e.g. Shuttleworth, 1993). In the broader definition of interception, we combine evaporation from leaf interception with wet surface evaporation occurring on the same day as the rainfall. The amount of interception thus defined is larger than amounts quoted in the literature based on the difference between rainfall and throughfall.

The importance of interception

Interception is one of the most underrated, and underestimated, processes in rainfall-runoff analysis. One could call interception the "Cinderella of Hydrology". She may be beautiful and rather straightforward, but apparently not interesting enough to be adequately represented in hydrological models. Some models even disregard interception completely (particularly event-based models, based on the simplified catchment model of Dooge, 1973, 2003), the argument being that it is generally a small proportion of the total evaporation. This disregard is a mistake, for several reasons.

Firstly, the amount of interception is not small. Beven (2001) states that evaporation from intercepted water on leaf surfaces in rough canopies can be very efficient and a significant component of the total water balance in some environments. Calder (1990) shows that in the upland forest catchments of Britain evaporation from interception amounts to 35% in areas with an annual rainfall of more than 1000 mm/a, but that it is higher in areas with lower rainfall, amounting to about 40-50% in areas with 500-600 mm/a. In Calder's definition, however, interception is merely the difference between rainfall and throughfall. But if we use the broader definition presented above, interception is considerably larger. After a rainfall event, not only the leaves of vegetation are wet, also the surface underneath (rock, soil, mulch layer, roads, build-up area, etc.), which becomes dry within the same day, particularly in warm climates. Moreover there are many stagnant pools that continue to evaporate until a day after the event. The additional wet surface evaporation can be as much as the interception by leaves, particularly in dry climates. All these interception processes are fast, having an average residence time in the order of one day.

Note that the wetted soil surface should not be considered part of the soil moisture that feeds the transpiration process. The wet surface (extending to several millimetres of soil depth) feeds back the intercepted water through direct evaporation and not via a delayed transpiration process. Even a stretch of dry sand, without vegetation, can intercept water. After a rainfall event a wet "crust" of soil is formed, underlain by dry sand, which dries out again within a day. This soil can intercept several millimetres of rainfall.

Transpiration is very different. First of all it is a physiological process intimately tied to CO_2 assimilation. The time scale of transpiration is determined by the soil moisture stock, which makes the time scale of the process much longer (average residence times varying between weeks and months depending on the soil depth). Finally, the process of transpiration does not change the isotope composition of the evaporated moisture, whereas evaporation of a water surface does. One can distinguish fast transpiration and delayed transpiration. Fast transpiration is from shallow rooted plants (typically grass and annual crops) with a time scale of less than a month; delayed transpiration is from deeply rooted plants (trees, shrubs, perennial crops), which have a time scale longer than a month. Fast transpiration only draws on the upper soil layer (until 50 cm depth), whereas delayed transpiration draws on deeper soil layers. Open water evaporation can be considered separately, when necessary, and is identifiable relatively simply.

Determining evaporation from interception

Computation of interception on an instantaneous basis is done by a Rutter model (Rutter et al., 1971), based on Eq. (1). For practical purposes, however, and in view of the typical time scale of the process where wetness due to a rainfall event evaporates within a time span of a day, interception is very well captured on a daily time scale. The daily process of interception is conveniently described as a threshold process, with a daily threshold *D* (mm/d). Daily interception (mm/d) is then compute as:

$$I = \min(P, D) \tag{2}$$

implying that if the rainfall is less than the threshold, the interception is equal to the rainfall and otherwise it is equal to the threshold value.

Monthly evaporation from interception can be determined very efficiently, even for poorly gauged catchments through De Groen's method. De Groen (2002) developed an analytical model for the computation of monthly interception based on the Markov property of daily rainfall[1] and using a daily interception capacity *D*.

$$I_m = P_m\left(1 - \exp\left(-\frac{n_r D}{P_m}\right)\right) \tag{3}$$

where I_m is the monthly evaporation from interception (mm/month), P_m the monthly rainfall (mm/month), and n_r is the number of raindays per month (d/month). She demonstrated that, as a result of the Markov property of daily rainfall, the number of raindays in a month is a function of the monthly rainfall.

$$n_r = \frac{30\, p_{01}}{1 - p_{11} + p_{01}} \tag{4}$$

where p_{01} is the probability of a rainday after a dry day and p_{11} is the probability of a rainday after a rainday. These probabilities appear to be power functions of monthly rainfall. These power functions can be derived from time series analysis of selected raingauges with daily observations. De Groen (1992) demonstrated that the coefficients of the power functions are representative for larger areas and can be interpolated between rainfall stations, similar to the the regional distribution of monthly rainfall. This is surprising, since daily rainfall is known to have a very small spatial correlation (a few km), but apparently the Markov property has a high one, of the same order of magnitude as monthly rainfall (100-1000 km).

[1] The Markov property implies that the probability that a certain day is a rainday depends purely on whether the previous day was a wet or a dry day.

Figure 2 shows the relative contributions of monthly interception (*I*) and transpiration (*T*) to total evaporation (*E*) in the Mupfure catchment. The Mupfure river, at Beatrice in Zimbabwe, drains a small catchment of 1215 km^2. It has an annual rainfall of about 800 mm/year. There is no substantial open water. The plots are based on monthly values over the period 1970-1979. The monthly interception has been computed by De Groen's formula with a threshold value of 4 mm/day. This may seem a large threshold, but it caters for more than the difference between rainfall and throughfall (including wet surface evaporation) and there is generally more than one rainfall event per day, each of which contributes to evaporation from interception. Pitman (1973) argues that interception in Southern Africa can be as much as 8 mm/day in forests. De Groen (2002) considers 2-5 mm/day appropriate, depending on the land use, but the true value is not exactly known. The use of a higher or lower value of *D* changes the partitioning between *I* and *T*. The transpiration is computed as the difference between the interception and the total evaporation, which was determined on the basis of a monthly water balance. As a result, Figure 2 gives an impression of how interception and transpiration relate and their order of magnitude, for different amounts of monthly rainfall.

As an aside: in Figure 2 one can distinguish scatter dots and dots that appear to follow a pattern (the drawn lines). The scatter dots that occur in the low rainfall months are the result of transpiration from soil moisture stocks built-up during the wet season, that are accessed by deeply rooted vegetation. The scatter dots in the months with high rainfall are caused by limited solar radiation constraining evaporation. The drawn curves represent the contributions of interception and transpiration to the fast evaporation, occurring within one month, i.e. interception and fast transpiration.

It can be seen that, overall in the Mupfure catchment, evaporation from interception is as significant as transpiration, and that in the wet months transpiration is dominated by fast transpiration (the drawn curve), as there is no moisture deficit and the soil moisture stock is being replenishment. More importantly, interception is dominant in wet months. Figure 3 shows the annual partitioning of rainfall into transpiration (*T*), runoff (*Q*) and interception (*I*), indicating that interception comprises a considerable amount of the annual rainfall, with a tendency for interception to dominate in very dry years.

Besides interception forming a considerable part of monthly evaporation, it is crucial for determining antecedent conditions in rainfall-runoff modelling. It is often said that during storm events, evaporation from interception is negligible as compared to other fluxes. This may be true during the event itself, which is of short duration, but it is untrue in relation to the build-up of the antecedent conditions. It is widely recognised that the success of event-based modelling depends to a very large extent on the antecedent conditions, particularly the distribution of the soil moisture in the unsaturated soil. If we want to get that right, it is important to split the rainfall into the effective part that contributes to soil moisture (and hence the rainfall-runoff process) and the ineffective part that does not, i.e. interception.

Finally, evaporation from interception is the most important process in moisture recycling to support continental rainfall. Figure 2 illustrates this. It shows that in months with high rainfall (i.e. the wet season), interception is an important mechanism. In dry months, transpiration is often dominant, but in these months (typically after the wet season) there are hardly any rainfall generating mechanisms to benefit from this feedback. Schuttleworth (1993) observed that half the evaporation from interception occurs during the storm itself, providing instant moisture feedback. Hence the moisture feedback to the atmosphere, which is such an important mechanism to support continental rainfall in the Sahel, and the Amazon (Eltahir and Bras, 1994; Savenije, 1995), relies primarily on interception. The reason why transpiration is relatively small in wet months is because part of the energy available for evaporation is consumed by the interception process, which precedes transpiration, and because solar radiation is inhibited by clouds in wet months.

Consequences of underestimating interception

The picture of the Mupfure basin may not be representative for other climatic regions, but it serves to make a point. Interception is an important mechanism that cannot be simply neglected or lumped with other evaporation mechanisms. Disregarding or underestimating interception can lead to serious modelling mistakes, particularly when one uses automated calibration techniques. If interception is modelled incorrectly, the error will be compensated by other parameters, to satisfy the goodness-of-fit criterion. If a range of interception thresholds is tested, then one may find a correlation between interception and other soil and groundwater parameters. Clearly such relations are spurious.

The most common mistake of lumping interception with transpiration leads to an over-dimensioning of the soil moisture stock. This can be seen easily. If the interception is forced through the transpiration process, a correct representation of the total flux and time scale in the model can only be achieved if the soil moisture stock is over-dimensioned. If transpiration and interception are of the same order of magnitude, then the modelled soil moisture stock should be double its 'real' value.

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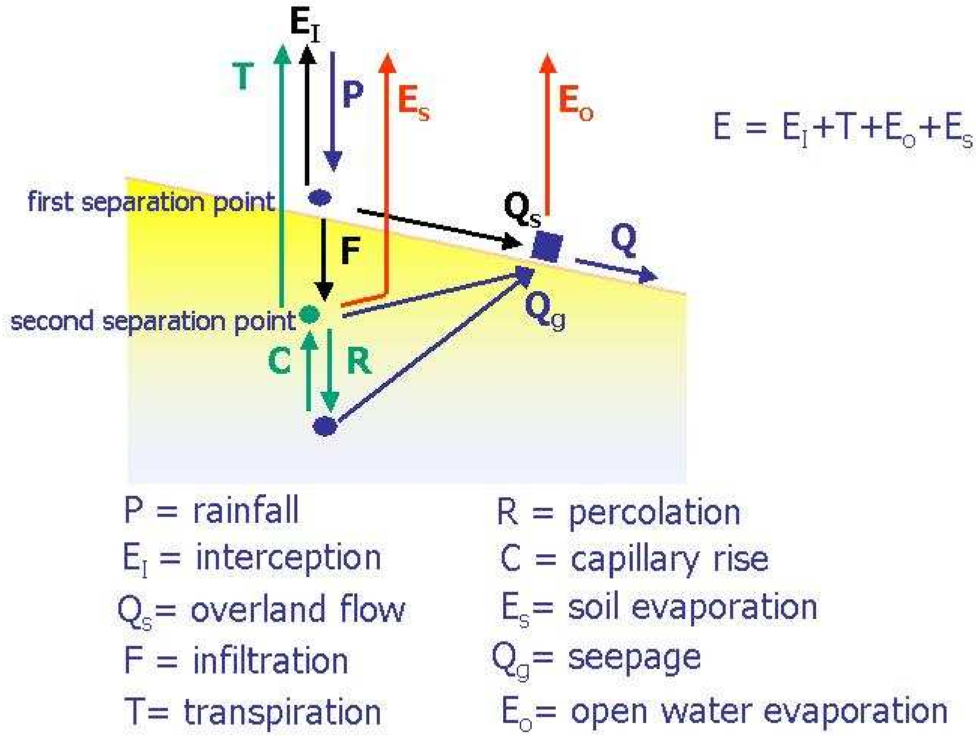

Figure 1 Separation points at the landscape interface.

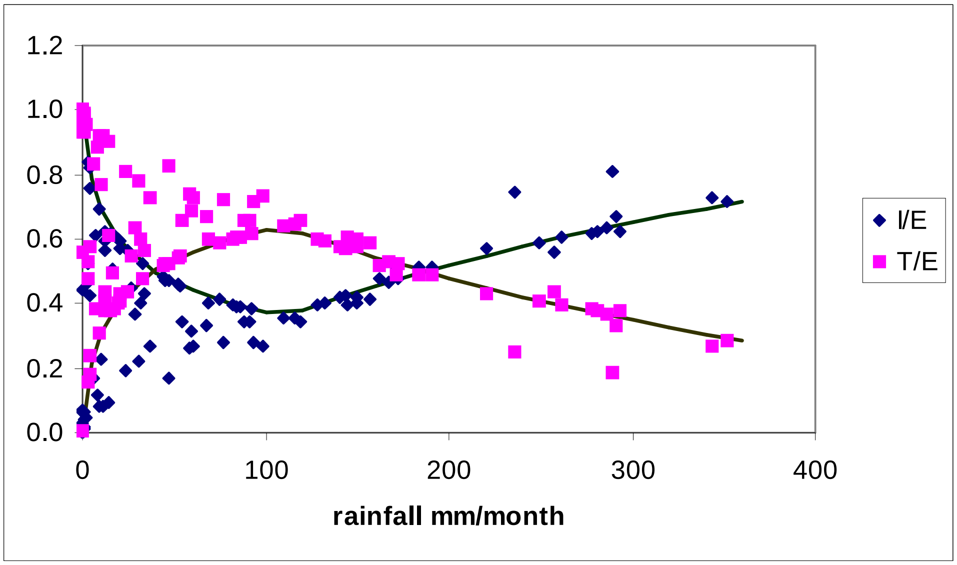

Figure 2 Relative contributions of interception (I) and transpiration (T) to monthly evaporation (E) in the Mupfure catchment in Zimbabwe, with D_d = 4 mm/day

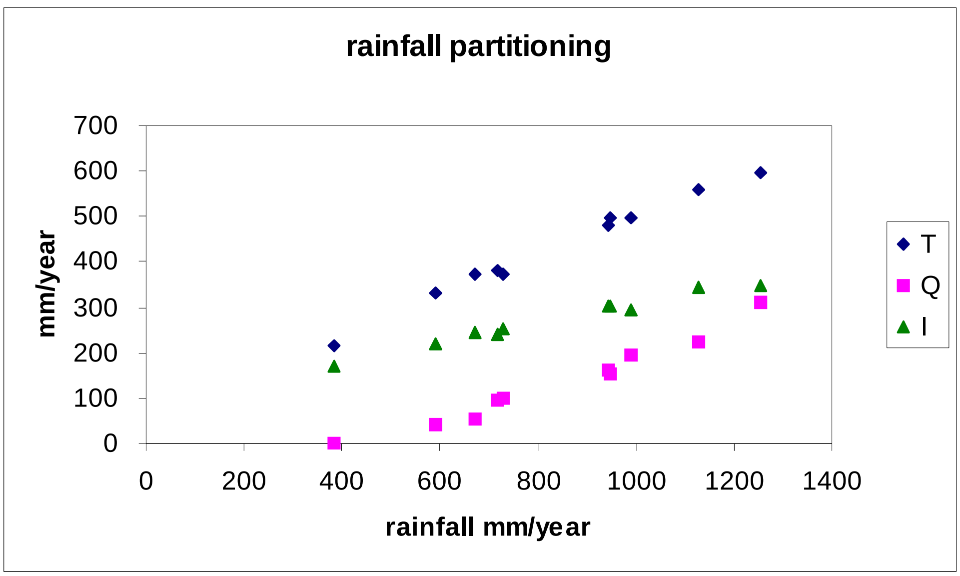

Figure 3 Annual rainfall partitioning into runoff (Q), interception (I) and transpiration (T), Mupfure basin at Beatrice, with D_d = 4 mm/day.