Hydrol. Earth Syst. Sci., 11, 695–701, 2007
www.hydrol-earth-syst-sci.net/11/695/2007/

Hydrology and Earth System Sciences

New technique to measure forest floor interception – an application in a beech forest in Luxembourg

A. M. J. Gerrits[1,2], **H. H. G. Savenije**[1], **L. Hoffmann**[2], **and L. Pfister**[2]

[1]Water Resources Section, Faculty of Civil Engineering and Geosciences, Delft University of Technology, P.O. Box 5048, 2600 GA Delft, The Netherlands
[2]Department Environment and Agro-biotechnologies, Centre de Recherche Public – Gabriel Lippmann, 41, rue du Brill, L-4422 Belvaux, Luxembourg

Received: 10 July 2006 – Published in Hydrol. Earth Syst. Sci. Discuss.: 22 August 2006
Revised: 8 December 2006 – Accepted: 20 December 2006 – Published: 17 January 2007

Abstract. In hydrological models, evaporation from interception is often disregarded, combined with transpiration, or taken as a fixed percentage of rainfall. In general interception is not considered to be a significant process in rainfall-runoff modelling. However, it appears that on average interception can amount to 20–50% of the precipitation. Therefore, knowledge about the process of interception is important. Traditional research on interception mainly focuses on canopy interception and almost completely denies forest floor interception, although this is an important mechanism that precedes infiltration or runoff. Forest floor interception consists partly of interception by dry soil, partly of interception by short vegetation (mosses, grasses and creeping vegetation) and partly of interception by litter. This research project concentrates on litter interception: to measure its quantities at point scale and subsequently to upscale it to that of a hydrotope. A special measuring device has been developed, which consists of a permeable upper basin filled with forest floor, and a watertight lower basin. Both are weighed continuously. The device has been tested in the Huewelerbach catchment (Luxembourg). The preliminary measuring results show that the device is working properly. For November 2004, evaporation from interception was calculated to be 14 mm of 42 mm throughfall (i.e., 34%).

1 Introduction

The process of rainfall interception and its successive evaporation is not always considered as a significant process in the hydrological cycle. This is partly due to the technical difficulties that are inherent to interception measurements (Lundberg et al., 1997; Llorens and Gallart, 2000). But also it is generally considered as a minor flux, particularly for the generation of floods, although interception strongly influences the antecedent soil moisture conditions, which are very important for the generation of floods (Roberts and Klingeman, 1970). Hence interception is regularly disregarded in hydrological models, or taken as a fixed percentage of the precipitation. As a result, after model calibration, interception is generally compensated by another process like transpiration or soil evaporation (Savenije, 2004).

Moreover, interception measurements generally concentrate on canopy interception whereas interception by understorey and forest floor can be as high or higher. Evaporation from interception can amount up to 20-50% of the precipitation. For example, Rutter et al. (1975) found canopy interception values of 12% of the precipitation for a defoliated oak and 48% for a Norway spruce forest in the United Kingdom. Bryant et al. (2005) also found comparable results for a different kind of forest in the southeast of the United States. For a pine, mixed, lowland hardwood, pine plantation and upland hardwood forest, Bryant et al. (2005) measured that respectively 22%, 19%, 18%, 18% and 17% of the rainfall was intercepted by canopy and successively evaporated. And Schellekens et al. (1999) found that about 50% of the gross precipitation evaporated from the canopy of a Tabonuco type forest in northeastern Puerto Rico. All these studies merely consider canopy interception. If forest floor interception is also taken into account the total amount of intercepted rainfall can be twice as much, as will be demonstrated. A remarkable difference between canopy and forest floor interception is the relatively small interception storage capacity for the canopy compared to the forest floor. On the other hand, the canopy has a larger evaporative potential compared to forest floor interception (Baird and Wilby, 1999).

1.1 Definition of interception

In the literature, interception is often defined in different ways: sometimes as a stock, sometimes as a flux or more

Correspondence to: A. M. J. Gerrits
(a.m.j.gerrits@tudelft.nl)

appropriately, as the entire interception process (Savenije, 2005). If only interception storage [L] is considered, interception is defined as the amount of rainfall which is temporarily stored on the land and evaporated shortly after and during the rainfall event. Actually, this is the interception capacity or water holding capacity. Examples of interception storage measurements are those of Kiss et al. (2005) and Putuhena and Cordery (1996). If the interception flux is considered, interception is defined as the amount of intercepted water, which is evaporated in a certain time [L T^{-1}]. When the interception process (I [L T^{-1}]) is considered, interception is defined as the part of the rainfall flux which is intercepted on the wetted surface after which it is fed back to the atmosphere. The interception process equals the sum of the change of interception storage (S_{int}) and the evaporation from this stock (E_{int}):

$$I = \frac{\mathrm{d}S_{\text{int}}}{\mathrm{d}t} + E_{\text{int}} \quad (1)$$

The time scale of the interception process is in the order of one day. After one day, it is fair to assume that the first term on the right hand side in Eq. (1) approximates zero, so $I = E_{\text{int}}$.

1.2 Forest floor interception review

Forest floor interception is the part of the (net) precipitation that is temporarily stored in the top layer of the forest floor and successively evaporated within a few hours or days during and after the rainfall event. The forest floor can consist of bare soil, short vegetation (like grasses, mosses, creeping vegetation, etc.) or litter (i.e., leaves, twigs, small branches).

In the literature, little can be found on forest floor interception, although some researchers have tried to quantify the interception amounts. Generally these methods can be divided into two categories (Helvey and Patric, 1965):

1. Lab methods, whereby field samples are taken to the lab and successively the wetting and drying curves are determined by measuring the moisture content.

2. Field methods, whereby the forest floor is captured into trays or where sheets are placed underneath the forest floor.

An example of the first category is that of Helvey (1964), who performed a drainage experiment on the forest floor after it was saturated. During drainage, the samples were covered and after drainage had stopped (24 h), the samples were taken to the lab, where the samples were weighed and successively dried until a constant weight was reached. By knowing the oven dry weight of the litter per unit area and the drying curve, the evaporation from interception could be calculated. In this way they found that about 3% of the annual rainfall evaporated from the litter. But what they measured was not the flux, but the storage capacity. Another example of lab experiments was carried out by Putuhena and Cordery (1996). First, field measurements were carried out to determine the spatial variation of the different forest floor types. Second, storage capacities of the different forest floor types were measured in the lab using a rainfall simulator. Finally, the lab experiments were extrapolated to the mapping step. In this way Putuhena and Cordery (1996) found average storage capacities of 2.8 mm for pine and 1.7 mm for eucalyptus forest floors.

Examples of the second category are for example carried out by Pathak et al. (1985), who measured the weight of a sample tray before and after a rainfall event. They found litter interception values of 8%–12% of the net precipitation. But also here, they measured the storage capacity, rather than the flux. Schaap and Bouten (1997) measured the interception flux by the use of a lysimeter and found that 0.23 mm day^{-1} evaporated from a dense Douglas fir stand in early spring and summer. Examples of measurements with sheets were done for example by Li et al. (2000), who found that pebble mulch intercepts 17% of the gross precipitation. Miller et al. (1990) found comparable results (16–18%) for a mature coniferous plantation in Scotland.

The device which is described in this paper and which measures evaporation from intercepted rainfall on the forest floor, belongs to the second category. The new device has been tested in a forest clearing in Westerbork (northeast of the Netherlands) and in a beech forest in the Huewelerbach catchment in the western part of Luxembourg. The set up in the Huewelerbach catchment measures interception of litter and the one in Westerbork measures interception of grass and mosses. The latter device measures transpiration as well and is therefore not considered in this paper. The first objective of the measurements is to obtain knowledge about the quantities of forest floor interception at point scale and later to upscale it to a hydrotope.

2 Materials and method

The Huewelerbach catchment (49.7° N 5.9° E) is a hill slope area in Luxembourg, which consists mainly of sandstone and has a basin area of about 2.7 km^2. The climate in Luxembourg is modified oceanic with mild winters and temperate summers. The average annual temperature is circa 9°C and the total rainfall is about 740 mm/a (Pfister et al., 2005). In the Huewelerbach catchment, an experimental plot of 0.0596 ha has been set up in a 120 year old beech (*Fagus Sylvatica*) forest with a density of 168 trees/ha (see Fig. 1). The interception device is placed underneath the canopy, so it essentially receives throughfall (T [L T^{-1}]). To measure the throughfall, a 3 meter long gutter is placed underneath the canopy and close to the device, which drains into a tipping bucket. Next to the interception device four pluviometers (I, II, III, IV) are installed, from which the average is calculated ($\overline{T}_{\text{pluvio}}$ [L T^{-1}]). The pluviometers are read manually every

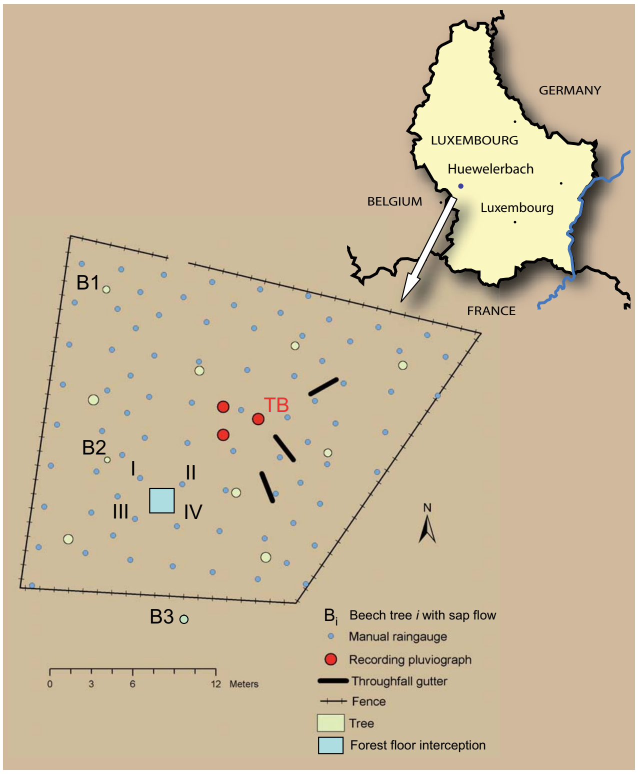

Fig. 1. Overview of the beech plot in the Huewelerbach catchment (Luxembourg).

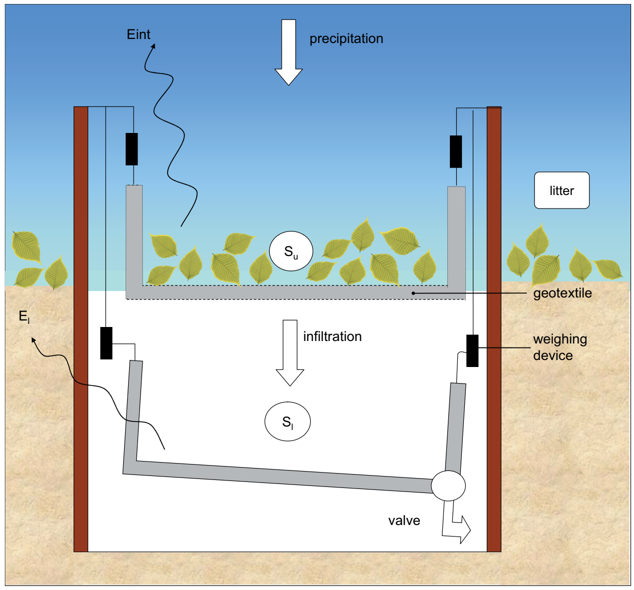

Fig. 2. Schematic drawing of the interception device in the Huewelerbach catchment with E_{int} the evaporation from interception, E_{l} the evaporation from the lower basin and S_{u} and S_{l} the storage in respectively the upper and lower basin.

1 or 2 weeks. To calculate the net rainfall (P_{net} [L T^{-1}]) on the interception device, the event-based pattern of the tipping bucket (TB) (T_{tb} [L T^{-1}]) is mapped on the average cumulated precipitation in the pluviometers. In formula form for $0 \leq t \leq i$:

$$P_{\mathrm{net}}(t) = T(t) = T_{\mathrm{tb}}(t) * \frac{\sum_{t=0}^{t=i} \overline{T}_{\mathrm{pluvio}}}{\sum_{t=0}^{t=i} T_{\mathrm{tb}}} \quad (2)$$

where i is the moment where the four pluviometers are read manually.

To measure evaporation from intercepted rainfall on the forest floor, a special device has been developed. The device consists of two aluminium basins, which are mounted above each other and are weighed accurately with 2 sets of 3 strain gauge sensors (see Fig. 2). One sensor consists of a metal ring where four strain gauges are mounted in the Wheatstone configuration. The upper basin is filled with forest floor and has a permeable bottom of geotextile, so water can percolate into the lower basin. A valve is installed in this lower basin, which empties every day for 10 min to avoid evaporation from the lower basin as much as possible. The space between the supporting structure and the aluminium basins is also minimized, in order to avoid evaporation by turbulent wind fluxes. In addition to the weight, the temperature is also measured in one of the lower strain gauge casings and saved on a data logger every minute.

To calculate the amount of evaporation from interception, a water balance is made of the system. When evaporation from the lower basin (E_{l} [L T^{-1}]) is neglected and the weight of the lower basin is corrected for the drainage from the valve (S_{l} [L]), evaporation of intercepted rainfall (E_{int} [L T^{-1}]) can be calculated as:

$$E_{\mathrm{int}}(t) = P_{\mathrm{net}}(t) - \left(\frac{\mathrm{d}S_{\mathrm{u}}}{\mathrm{d}t} + \frac{\mathrm{d}S_{\mathrm{l}}}{\mathrm{d}t} \right) \quad (3)$$

where S_{u} and S_{l} are respectively the storage of the upper and the lower basins [L], which are obtained by dividing the weight of the basins [M] by the density of water [M L^{-3}] and the surface area [L^2] of the basin.

In the Huewelerbach catchment, the rectangular basins have a surface area of 1.00 m^2 and the upper basin is filled only with leaves (no soil) from the beech canopy (i.e., litter interception). A photo of the set up can be seen in Fig. 3.

3 Results and discussion

The first results of the interception device in the Huewelerbach are presented in Fig. 5. The data have first been aggregated from a one minute time step to a 15 min time step using the moving average method to cancel out measuring noise. The raw measuring data of the interception device (with a time step of one minute) and the meteo data can

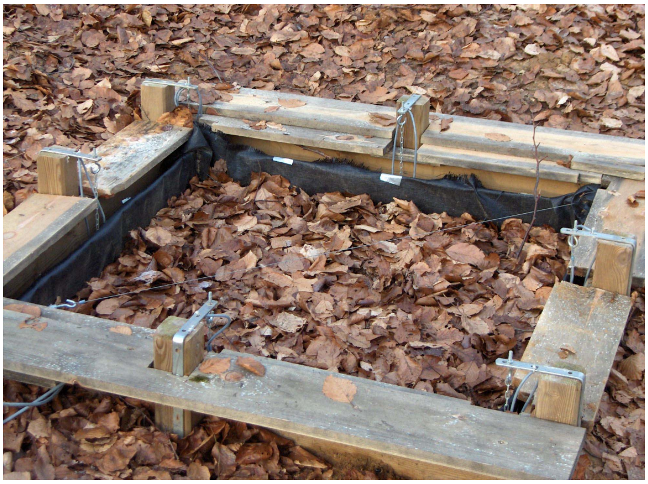

Fig. 3. Interception device in the Huewelerbach catchment on January 2006. The upper basin is filled with leaf litter.

be obtained from the DARELUX-repository (http://devcms.library.tudelft.nl/DLUI2/hessd001.html).

From the graph, it can be seen that the device works properly. After a rainfall event, the weight of the upper basin increases, and the weight of the lower basin also increases if the rainfall event is large enough to saturate the upper basin. The working of the valve can also clearly be seen by the sudden drop of the weight of the lower basin. As a check, it is possible to do a water balance verification by summing up all weight increases in both basins (accumulated S_u+S_l), which should be equal to the sum of the net precipitation. An example of such verification is given in Fig. 4. There is often a small difference between the two, caused by things like evaporation during the rainfall event, measuring noise, falling branches and/or leaves, dew, heterogeneity of throughfall (due to canopy structure), passing of small animals (like birds or rabbits) on the upper basin, etc. In Fig. 5, the amount of evaporated interception is calculated for the Huewelerbach by Eq. (3). For November 2004, 34% of the net rainfall (i.e., throughfall) has evaporated from the litter (i.e., 14 mm interception of 42 mm throughfall). Because we want to compare the results with storage capacity estimates from the literature, we apply a simple threshold model described by Savenije (1997):

$$E_{\text{int}} = \min(P_d, D) \tag{4}$$

This model describes the daily interception as a threshold process with P_d the daily rainfall [L T^{-1}] and D the daily interception threshold [L T^{-1}]. The threshold D is calibrated so that the monthly interception sum of the threshold model is equal to the intercepted month sum of the observed interception. The calibrated estimate for D of 1.5 mm day^{-1} compares well with the estimate of 1.7 mm for an eucalypt floor from Putuhena and Cordery (1996). The large difference with the results of Helvey (1964), who found that only 3% of the annual rainfall evaporated by the litter, can first be explained by the fact that only events which are large enough to saturate the forest floor were taken into account. In this way a large part of the litter interception is neglected, especially in temperate climates. Second, it is quite difficult not to disturb field samples when taking them to the lab. Third, evaporation during the rainfall events is not taken into account, which is also the case for the method of Pathak et al. (1985), who measured that 8–12% of the net precipitation was evaporated. Despite these arguments, Helvey and Patric (1965) stress that the difference is caused by the "interface effect". This is probably not the case for this measuring setup, because the used geotextile is very permeable and simulates real atmospheric pressure conditions between litter and soil. A comparison with the results of Schaap and Bouten (1997) and Li et al. (2000) is quite difficult, because they measured pine and pebbles, respectively, which do not have the storage capacity of leaves, which explains their lower estimates.

3.1 Temperature correction

Although the interception device generally works well, there are unfortunately some minor problems. As can be clearly seen in Fig. 6, during a dry period (for example the last week of June or the second week in July) there are some daily increases in the upper basins, which are not caused by rainfall. This daily pattern can be partly explained by dew. However the observed increases are of a higher magnitude. Another explanation is the effect of temperature (T) variation on the sensors. Because the strain gauges are mounted on a metal ring, which expands when the temperature increases and which reacts similarly to a decrease in weight, the sensors measure a lower weight than in reality. To correct the observed data for this effect, the relation between temperature and the output of the sensor should be found. Therefore, a linear regression has been applied for a dry period, to be sure that the variation in observed weight is only due to temperature variation. It appears that a linear relation exists; however, a time lag ρ [T] occurs between temperature change and the reaction on the sensors due to hysteresis in the cooling and heating of the sensors. Table 1 presents the regression values, which are successively used to correct the data with Eq. (5), where S_{cor} is the weight after the correction for temperature [M], S_{obs} the sensor output [M] and t the time step [T]. The differences between the time lags are partly due to the fact that the temperature sensor is not mounted on the metal ring itself, but close to it, and partly because the sensors do not all receive the same amount of radiation.

$$\begin{aligned} S_{\text{cor}}(t) = S_{\text{obs}}(t) - S_{\text{obs}}(t-1) + S_{\text{cor}}(t-1) \\ -\alpha\,(T(t+\rho) - T(t-1+\rho)) \end{aligned} \tag{5}$$

After the correction was applied on the data, only a slight improvement could be observed. Hence for future

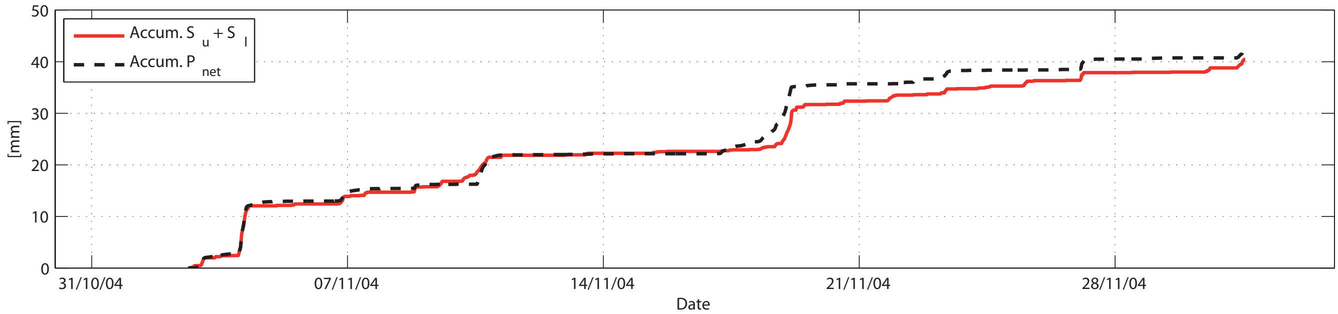

Fig. 4. Water balance verification of data of the Huewelerbach catchment for November 2004. A threshold of 0.04 mm is used to reduce the effect of measuring noise.

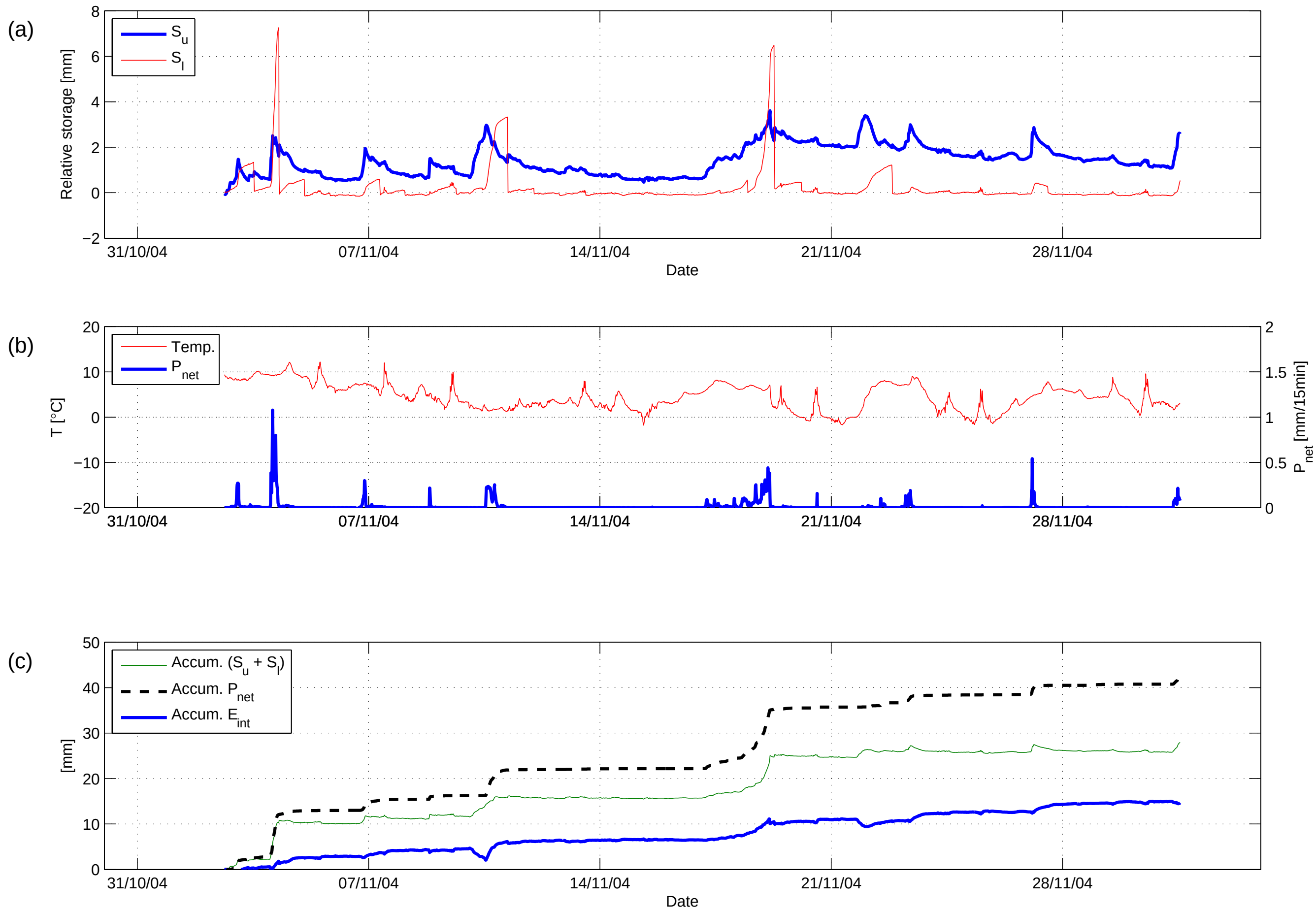

Fig. 5. Measuring results of the Huewelerbach catchment for November 2004. **(a)** Storage in the upper and lower basin compared to initial situation (relative storage); **(b)** Meteorological data (net rainfall and temperature); **(c)** Cumulated evaporation from interception compared to total net rainfall.

experiments, new sensors, which are less temperature sensitive, will be built. The new sensors will also be tested in a climate room to know the relation between temperature and sensor output. Second, an extra sensor (dummy) will also be installed on which a fixed weight is mounted, so the relation between temperature and sensor output is always known.

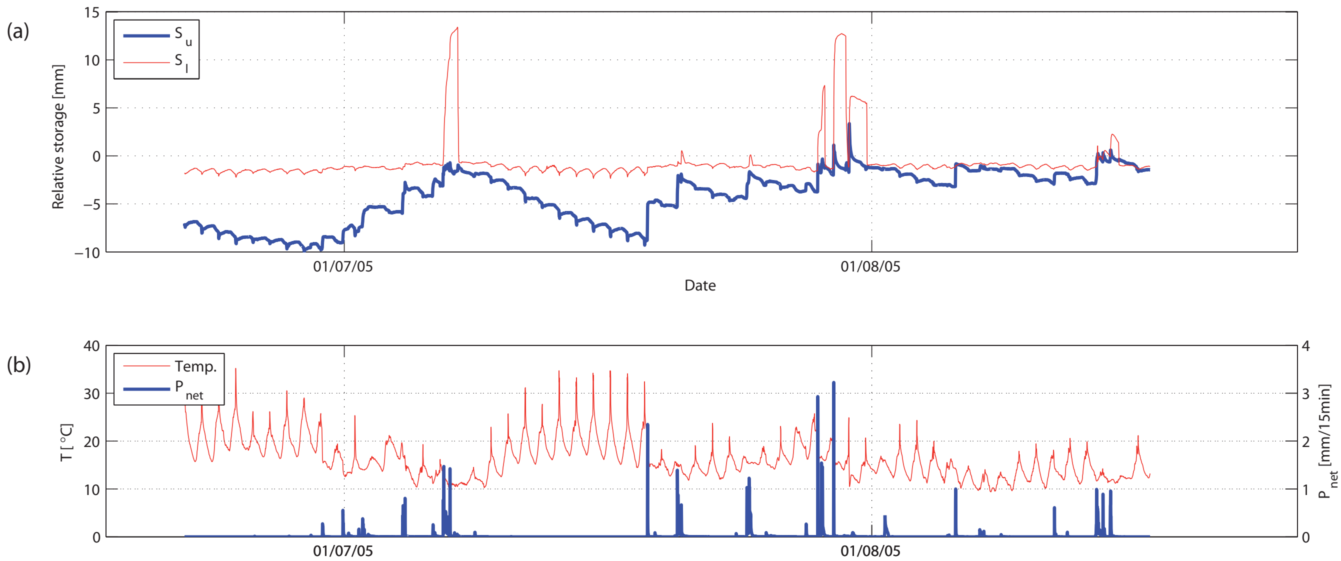

Fig. 6. Measuring results of the Huewelerbach from 21 June until 17 August 2005. **(a)** Storage in the upper and lower basin compared to initial situation (relative storage); **(b)** Meteorological data (net rainfall and temperature).

Table 1. Linear regression results with time lag.

Sensor	α [gr °C^{-1}]	ρ [min]	R^2
upper 1	–0.047	–131	0.10
upper 2	–0.071	–38	0.14
upper 3	–0.074	–34	0.14
lower 4	–0.277	–25	0.95
lower 5	–0.212	–23	0.93
lower 6	–0.150	–46	0.79

3.2 Improvements of the device

For the future, it would be interesting to look after the long term behaviour of the interception device. At the moment, this is unfortunately not yet possible due to different kinds of equipment failure, which caused gaps in the time series. A lot of data was lost due to valves congested by sand, leaves, etc. As a result, the amount of percolated water was not registered. This malfunction has been solved by installing a new valve with a larger diameter and by placing a filter before the valve entrance, lowering the chance of congestion. The first results look promising, so research can be done on interception throughout the seasons, to study the effect of oxidation of the leaves and vegetation growth.

4 Conclusions

The preliminary measurements of the interception device look very promising. However, for the future some fine tuning on things as the working of the valve and on the temperature influence will still be necessary. However, the new valve, the dummy and the new sensors will solve most of the problems.

The obtained result for evaporation from beech litter interception (14 mm of 42 mm net precipitation in one month (34%)) in the Huewelerbach catchment is quite high compared to the literature, particulary if we realise that it was measured during the European autumn (November). However, this value can be explained by 1) taking into account the rainfall events which are not large enough to saturate the litter, 2) by not disturbing the local water content conditions by working in the field, and 3) by taking evaporation during the rainfall event into account.

From these preliminary and limited results it can be concluded that forest floor interception is a significant process in the hydrological cycle and therefore should be included in hydrological models. Especially because interception has an effect on the antecedent moisture conditions, which are important for the generation of floods. If interception is not properly accounted for in a model, the model can of course be adjusted by calibration, but then the internal state variables are wrong and not physically based. In that case, the interception process is most likely compensated by another process such as for example transpiration or soil evaporation by increasing the soil moisture storage capacity. As a result, the function describing the transpiration as a function of the soil moisture is wrong.

For the future it will be interesting to look into the long term behaviour of the interception process to know for example how the process of interception changes over the seasons, how large the influence is of falling leaves and oxidation, how vegetation growth influences the measurements, etc. Furthermore it would be interesting to investigate the effect of rainfall intensity on the relatively amount of intercepted rainfall.

Acknowledgements. The authors would like to thank the Ministry of Culture, Higher Education and Research of Luxembourg and Delft Cluster, the Netherlands, for their support of this research. Furthermore, we thank the DARELUX-project for making the measuring data publicly available for verification and further research. We thank K. van Beek for designing the sensors and logger, and we thank U. Brandt for his MSc. work on the first development of the interception device.

Edited by: M. Mikos

References

Baird, A. J. and Wilby, R. L.: Eco-hydrology – Plants and water in terrestrial and aquatic environments, Routledge, 1999.

Bryant, M. L., Bhat, S., and Jacobs, J. M.: Measurements and modeling of throughfall variability for five forest communities in the southeastern US, J. Hydrol., 312, 95–108, 2005.

Helvey, J. D.: Rainfall interception by hardwood forest litter in the southern Appalachians, U.S. Forest Service Research Paper SE, 8, 1–8, 1964.

Helvey, J. D. and Patric, J. H.: Canopy and litter interception of rainfall by hardwoods of Eastern United States, Water Resour. Res., 1, 193–206, 1965.

Kiss, K. A., Gribovski, Z., and Kalicz, P.: Rainfall interception by forest canopy and forest litter in three different forest ecosystems at the eastern border of the Alps, Geophys. Res. Abstracts, 7, 05430, 2005.

Li, X. Y., Gong, J. D., Gao, Q. Z., and Wei, X. H.: Rainfall interception loss by pebble mulch in the semiarid region of China, J. Hydrol., 228, 165–173, 2000.

Llorens, P. and Gallart, F.: A simplified method for forest water storage capacity measurement, J. Hydrol., 240, 131–144, 2000.

Lundberg, A., Eriksson, M., Halldin, S., Kellner, E., and Seibert, J.: New approach to the measurement of interception evaporation, J. Atmos. Oceanic Technol., 14, 1023–1035, 1997.

Miller, J. D., Anderson, H. A., Ferrier, R. C., and Walker, T. A. B.: Comparison of the hydrological budgets and detailed hydrological responses in two forested catchments, Forestry, 63, 251–269, 1990.

Pathak, P. C., Pandey, A. N., and Singh, J. S.: Apportionment of rainfall in central Himalayan forests (India), J. Hydrol., 76, 319–332, 1985.

Pfister, L., Wagner, C., Vansuypeene, E., Drogue, G., and Hoffmann, L.: Atlas climatique du Grand-Duche de Luxembourg, Johnen-druck GmbH & Co, Bernkastel-Kues, 2005.

Putuhena, W. and Cordery, I.: Estimation of interception capacity of the forest floor, J. Hydrol., 180, 283–299, 1996.

Roberts, M. C. and Klingeman, P. C.: The influence of landform and precipitation parameters on flood hydrograph, J. Hydrol., 11, 393–411, 1970.

Rutter, A. J., Morton, A. J., and Robins, P. C.: A predictive model of rainfall interception in forests. II Generalization of the model and comparison with observations in some coniferous and hardwood stands, J. Appl. Ecol., 12, 367–380, 1975.

Savenije, H. H. G.: Determination of evaporation from a catchment water balance at a monthly time scale, Hydrol. Earth Syst. Sci., 1, 93–100, 1997, http://www.hydrol-earth-syst-sci.net/1/93/1997/.

Savenije, H. H. G.: The importance of interception and why we should delete the term evapotranspiration from our vocabulary, Hydrol. Processes, 18, 1507–1511, 2004.

Savenije, H. H. G.: Water Encyclopedia: Surface and Agricultural Water, chap. Interception, Wiley Publishers, 2005.

Schaap, M. G. and Bouten, W.: Forest floor evaporation in a dense Douglas fir stand, Journal of Hydrology, 193, 97–113, 1997.

Schellekens, J., Scatena, F. N., Bruijnzeel, L. A., and Wickel, A. J.: Modelling rainfall interception by a lowland tropical rain forest in northeastern Puerto Rico, J. Hydrol., 225, 168–184, 1999.