# Assessment of Frequency and Areal Extent of Overland Flow Generation in a Forested Mountain Catchment

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**Abstract**: Short time rainfall and throughfall measurements in the period May–October 2009, and the calculated saturated hydraulic conductivities of soils and isotopic hydrograph separations in August 2009 were used to estimate the frequency of the infiltration excess overland flow generation and the extent of saturated areas producing the saturation excess overland flow in the forested mountain catchment of the Jalovecký Creek, Western Tatra Mountains, northern Slovakia. The rainfall intensities exceeding 0.2 mm per 10 min occured only in 2–4% of all data measured. Saturated hydraulic conductivities ($K_S$) of soils were calculated by means of four methods based on the relationship between $K_S$ and soil texture. The comparison of $K_S$ with the measured rainfall intensities indicated that the infiltration excess overland flow could have been generated for 0–10% of the rainfall intensities measured. Isotopic hydrograph separation by means of the deuterium isotope indicated that the areas, where the saturated excess overland flow could have occurred, represented about 2–13% of the catchment during the analysed events. Despite the uncertainties connected with the assessments, the results are consistent with empirical knowledge of the catchment and limited older data.

**Keywords**: isotopic hydrograph separation; mountain catchment; rainfall intensity; runoff generation; soil hydraulic conductivity

The progress in the knowledge of the runoff generation in small catchments since the 1960' has resulted in a situation when the existence of different runoff components such as the overland flow, subsurface stormflow, baseflow, groundwater flow, and different mechanisms of their generation (e.g. saturation and infiltration excess overland flows, groundwater ridging, translatory flow, etc.) is generally accepted (e.g. Bonell 1993; Buttle 1998) and used in hydrological analyses. The recognition of the importance of the subsurface stormflow in flood generation along with the concept of variable source areas (Hewlett & Hibbert 1967; Hewlett & Nutter 1970) was close to being a "Copernican revolution" in understanding of the stormflow generation (Bonell 1993). A number of studies since the 1960' have demonstrated that in most humid temperate catchments the overland flow does not occur very often. However, the field recognition of the individual flow components (e.g. Šanda & Císlerová 2009) is not so common in research studies. This is due to the necessity of the deployment of much instrumentation and a very variable nature of the runoff generation mechanisms, some of which are still not well understood. Quantification of the vague term "not very often" could therefore be useful.

The generation of the overland flow (either saturated-excess or infiltration-excess overland flow) significantly depends on the soil properties, mainly on the hydraulic conductivity of the upper soil layer, and their distribution within a catchment. There

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Supported by the Scientific Grant Agency (VEGA), Grant No. 2/0079/08, by the IAEA, Project No. 12958/R0, and by the Ministry of Education, Youth and Sports of the Czech Republic, Project No. MSM 6840770002.

are many evidences, that hydraulic parameters of soils dominantly influence the water flow in a catchment (e.g. Chappell & Ternan 1992).

The studies dealing with hydrological modelling often state that the model simulations are most sensitive to the saturated hydraulic conductivity ($K_S$) of soil layers. Due to the difficulties, ambiguities, limited representativness, and time demands of the hydraulic properties measurement on the catchment scale, indirect methods are often used. These are typically based on the retention curves or hydraulic conductivity estimation based on the physical properties of soils (e.g. Clapp & Hornberger 1978; Gupta & Larson 1979; van Genuchten 1980; Arya & Paris 1981; Saxton *et al.* 1986).

The comparison of the rainfall intensities in the open area and in the forest with hydraulic characteristics of the soils could help to quantify the possibility of the generation of infiltration excess overland flow (also called Hortonian overland flow). Such a knowledge would, for example, allow indirect validation of the distributed hydrological models. On the other hand, it would help to determine the role of vegetation in a particular catchment as well. Another mechanism of the overland flow generation, i.e. the saturated excess overland flow, can be roughly estimated on the catchment scale from isotopic hydrograph separation. The estimation is based on the assumption that all new water forming the hydrograph comes from the saturated areas which occur in the catchment. New water component represents the water coming from the rainfall or snowmelt which initiated the studied runoff event. Isotopic hydrograph separation is a tool which substantially contributed to the change of ideas on runoff generation (e.g. Bonell 1993; Rodhe 1998). Although it was first time used already in the 1970', the boom in the application of isotopes and other tracers (chemicals) in hydrograph separations occured in the 1980' and 1990' (a number of references can be found e.g. in Rodhe 1998 and Genereoux & Hooper 1998). Isotopic hydrograph separation became later more criticised for its simplified assumptions (e.g. Burns 2002). It is obvious that as any other method, also isotopes have limitations. Yet, isotopic hydrograph separation can provide a rough estimate of the spatial extent of saturated areas which generate the saturated excess overland flow in the catchment.

The paper has the following objectives:

- assessment of the frequency of possible generation of infiltration excess overland flow in an open area and in a forest based on the measured rainfall intensities and calculated saturated hydraulic conductivity of the soils ($K_S$);
- calculation of the extent of areas generating a saturation excess overland flow in a relatively dry summer month by means of isotopic hydrograph separation.

## MATERIAL AND METHOD

### Catchment description

The study was conducted in the Jalovecký Creek catchment, the Western Tatra Mountains, northern Slovakia. The catchment area is 22.2 km$^2$, its mean altitude is 1500 m a.s.l. (the altitude ranges from 820 m up to 2178 m a.s.l.). The mean slope of the catchment is 30°. The bedrock is represented by crystalline rocks (schist, paragneiss, migmatite) and granodiorites which form 48% and 21% of the catchment, respectively. A small part of the catchment (about 7% of the catchment area), is made up by Mesozoic rocks (mainly limestone and dolomite). About 24% of the catchment is covered by Quaternary sediments. The main types of soil are Cambisols, Podzols and Lithosols. Rendzinas occur on Mesozoic rocks. All soils have a high skeleton content, often reaching values of 40–50% and more (Kostka & Holko 1997). The forest (mostly spruce), dwarf pine and alpine meadows, including bare rocks on the steepest slopes, cover 44, 31, and 25% of the catchment area, respectively. Most of the forest is over 100 years old.

Hydrological research in the catchment has been conducted since 1986. Mean annual precipitation is 1570 mm, mean annual runoff reaches 1004 mm. More detailed description of the catchment can by found e.g. in Holko and Kostka (2006, 2010). The observation network used in this study is shown in Figure 1.

### Rainfall measurements

Open area rainfall and throughfall were measured by tipping bucket rain gauges located at 1500 m a.s.l. and 1420 m a.s.l., respectively, from 13 May until 13 October 2009. Our previous measurements (Holko *et al.* 2009) revealed high variability of interception even at the same typical locations (forest window, dripping zone, near stem zone).

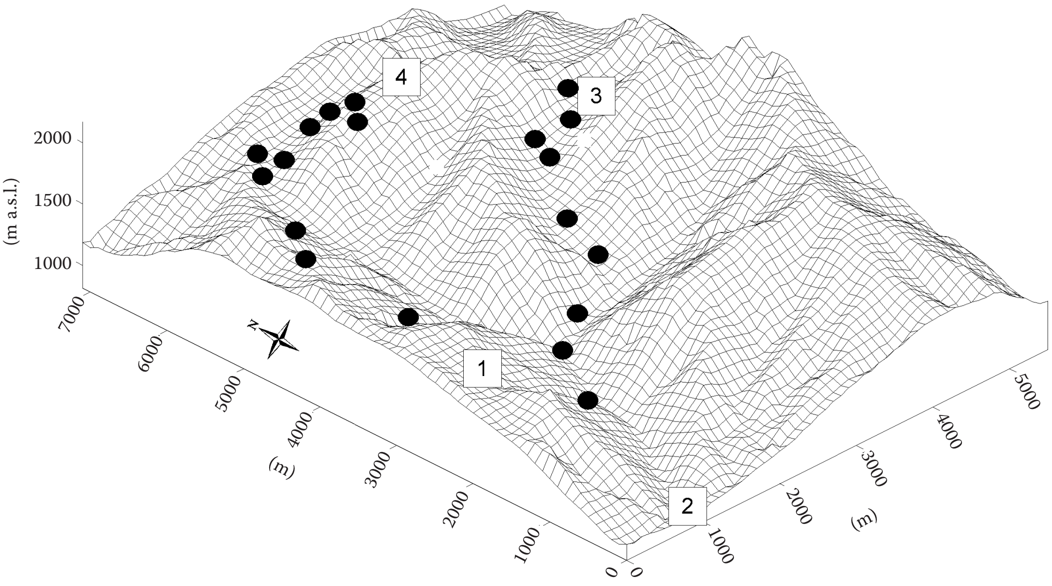

Figure 1. The Jalovecký Creek catchment and location of the observation network used in this study; 1 – open area precipitation and throughfall measurements, soil samples, altitude 1500 m a.s.l.; 2 – discharge, precipitation measurements, altitude 820 m a.s.l.; 3 – precipitation measurements, soil samples, altitude 1775 m a.s.l.; 4 – precipitation measurements, soil samples, altitude 1900 m a.s.l.; other locations of the soil sampling are shown by the black circles

The tipping bucket rain gauge in the spruce forest was therefore situated in a forest window which showed the smallest spatial variability of throughfall. Other tipping bucket raingauges (only in the open area) were situated at the altitudes of 820 m, 1775 m and 1900 m a.s.l. (Figure 1).

### Saturated hydraulic conductivity

The rainfall measurements at the sites, described in Figure 1 and in the previous paragraph, were compared with the calculated hydraulic conductivities ($K_S$) of the soils to estimate whether and how often the infiltration excess overland flow could have occurred in the catchment in the period of June–September 2009. The idea was based on the known fact that the velocity of precipitation infiltration quickly decreases and after some time it asymptotically reaches the value of the saturated hydraulic conductivity. $K_S$ was therefore used as a rough indicator of the conditions under which the infiltration excess overland flow could have been generated.

A number of methods are used to calculate the hydraulic characteristics of soils. The results provided by various methods may substantially differ. It is also known that the hydraulic characteristics of the same soil types may vary within a very large range of values in small areas. It is therefore necessary to select the methods which are the most appropriate for a given area, take into account the available data, and keep in mind that uncertainty always exists in the results. In this study, we used the indirect methods of $K_S$ calculation based on the relationships between the characteristics of the soil texture and $K_S$. Due to the large variability of the possible results depending on the available data and method applied, several methods were used to calculate $K_S$. The simplest one was that proposed by Cosby *et al.* (1984) who estimated $K_S$ from the known percentage of sand $p_S$ using the regression equation:

$$\log_{10}K_S = -0.884 + 0.0153 \times p_s \qquad (1)$$

where:

$K_S$ – saturated hydraulic conductivity (inch/h)

Another method was that proposed by Pucket *et al.* (1985) who found that the percentage of clay-sized particles was the best predictor of $K_S$ ($R^2 = 0.77$):

$$K_S = 4.36 \times 10^{-3} \times \exp(-0.1975C) \qquad (2)$$

where:

$K_S$ – expressed in cm/s

$C$ – clay-sized particles (%) in the soil sample

Saxton *et al.* (1986) derived the following equation for $K_S$:

$$K_S = 2.778 \times 10^{-6} \{\exp [12.012 - 0.0755 (\% \text{ sand}) + [-3.8950 + 0.03671 (\% \text{ sand}) - 0.1103 (\% \text{ clay}) + 8.7546 \times 10^{-4} (\% \text{ clay})^2] (1/\Theta_{\text{sat}})]\} \quad (3)$$

$$\Theta_{\text{sat}} = 48.9 - 0.126 \times p_s \quad (4)$$

where:

$K_S$ – expressed in m/s

$\Theta$ – soil water content ($\text{m}^3/\text{m}^3$)

Finally, the PLOTPF module of the soil-vegetation-atmosphere-transfer model SOIL (Jansson 1990, 1991) was used to calculate $K_S$. PLOTPF calculates $K_S$ from the data on the texture of the soil profile (7 grain-size classes) and the humus content.

Several data sources provided necessary soil data (grain-size distribution, organic matter content and/or bulk density) for the catchment studied. They included the Forestry Management Plan, soil research performed in the neighbouring mountain catchments by other scientists (Pelíšek 1956, 1973; Kňazovický 1970) and our own sampling in the catchment at 22 locations at different altitudes (Figure 1).

### Isotopic hydrograph separation

The advantage of isotopic hydrograph separation is that, despite the uncertainties, isotopes are conservative traces. This is not valid for some other separations, e.g. by chemicals or water conductivity. Principally, isotopic hydrograph separation is limited to flood events (e.g. Genereux & Hooper 1998). Several events should therefore be separated to obtain more representative results. Isotopic sampling is relatively time demanding. Especially the sampling of rainfall, which can not be automated so easily, needs more effort in larger catchments. Isotopic hydrograph separation is therefore usually performed only during shorter periods. In this study, we had been collecting samples for one month, which is a relatively long period of detailed sampling. Isotopic hydrograph separation by means of deuterium was performed for the rainfall-runoff events in August 2009. Although the runoff variability in the studied catchment in the warm period of the year (June–September) is usually high, a period of lower runoff often occurs in August (Holko & Kostka 2006). It may create favourable conditions to study the individual runoff events which are not interrupted by the subsequent rains and resulting runoff events. August 2009 was relatively dry and only several, relatively simple events occurred. The contribution of the pre-event runoff component was calculated from the well-known mixing formula as:

$$Q_p = Q_t (\delta_t - \delta_e)/( \delta_p - \delta_e) \quad (5)$$

where:

$Q$ – discharge

$\delta$ – $\delta^2$H value

$t, e, p$ – denote total (values measured at the catchment outlet), event (contribution from rainfall), and pre-event (contribution from the water which was present in the catchment before the rainfall) components, respectively

The altitude effect in the isotopic composition of precipitation is known to be important in the mountain catchment studied (Holko 1995). Several rain gauges situated at different altitudes (570, 750 and 1500 m a.s.l.) were therefore used to monitor the isotopic composition of precipitation on daily time step. The rain gauge in the spruce forest (at the altitude of 1420 m a.s.l., i.e. close to the forest line) was used to monitor the isotopic composition of throughfall. The isotopic composition of event water ($\delta_e$ in Eq. (5)) was estimated:

(a) as equal to the isotopic composition of rainfall sampled at the catchment mean altitude of 1500 m a.s.l. (site 1 in Figure 1);

(b) from the altitude gradient of $\delta^2$H in rainfall considering the influence of vegetation. First, $\delta^2$H in the elevation zones (every 100 m of elevation) was calculated using the altitude gradient for each rainfall event. Above 1500 m a.s.l., the value measured in the raingauge situated at 1500 m a.s.l. was given. Then, the enrichment taken from the measurements of the open area rainfall and throughfall (site 1 in Figure 1) was applied to all elevation zones up to 1500 m a.s.l. which is approximately the altitude of the forest line. The isotopic composition of the catchment rainfall ($\delta_e$) was then calculated as a weighted average using the areas of elevation zones as weights.

The differences in $\delta_e$ between (a) and (b) are shown in Figure 3 and Table 3.

Stream water samples were collected during August 2009 every 6 h during the periods without events and every 2 h during the events. Two alternative values of $\delta^2H$ of the pre-event water ($\delta_p$) were used in hydrograph separations. For $\delta_e$ described above as (a), $\delta_p$ was equal to the $\delta^2H$ value of the stream at the catchment outlet before the first event and it remained constant for all separated events. For $\delta_e$ described above as (b), $\delta_p$ was taken from the spring samples (Figure 3, Table 3). The spring is located close to the Jalovecký Creek and, at the same time, near the catchment outlet. It drains to the Jalovecký Creek and has proven deeper circulation (by means of several years of water conductivity, water temperature, and isotopic composition measurements).

The calculated contributions of the event water during the events were used to estimate the areal extent of the saturated areas in the catchment which could by theory produce the saturated overland flow (Rodhe 1987):

$$A = \frac{Q}{P} X_e \tag{6}$$

where:

$A$ – catchment area (%) which generated saturation excess overland flow

$Q$ – catchment runoff (mm)

$P$ – catchment precipitation (mm)

$X_e$ – event water fraction (%)

The collected water samples were analysed for $\delta^2H$ and $\delta^{18}O$ by means of the Liquid Water Isotope Analyser (Penna *et al.* 2010). Before further processing, the positions of the samples with regard to the mean meteoric water line (Craig 1961) were checked to exclude the samples which were affected by evaporation.

## RESULTS

### Rainfall intensities and saturated hydraulic conductivities

The 10-min data showed that the rainfalls with intensities higher than 0.2 mm/10 min occurred only in 2–4% of the cases. Maximum intensities at different sites varied from 6.2 to 14.8 mm per 10 min. The correlation matrix of the 10-min rainfall at sites 1–4 indicated that the short-time rainfall had several spatial patterns. The best correlations were found between sites 1 and 2 and sites 3 and 4.

Mean intensities calculated for the individual rainfall events are shown in Figure 2. Figure 2 also shows that the correlation of intensities in the open area and in the forest was not very good although the intensities in the open area were mostly higher than those in the forest. The relationship between the throughfall and open area rainfall (for the whole rainfall events, not for the 10-minutes data) can be expressed by the following equation:

$$\text{Throughfall} = 0.981 \times \text{rainfall} - 2.055 \; (n = 59, R^2 = 0.816) \tag{7}$$

The values of $K_S$ for the soils that occur in the Jalovecký Creek catchment as calculated by the four different methods are given in Table 1. The values given by the approach used by Saxton provided subjectively the most reasonable values. It utilised most of the available grain-size and organic matter content data while the other methods used only the percentage of sand (Cosby) and clay (Pucket).

The ferro-humic podzol representing loamy-sand soil texture is the dominant soil type in the Jalovecky Creek catchment. Therefore, we used the $K_S$ of the loamy-sand soil calculated by the approach of Saxton to assess the frequency of the possible occurrence of infiltration excess overland flow for the individual 10-min rainfall intensities. The numbers of 10-min rainfall compartments exceeding the selected values of $K_S$ are given in Table 2. The comparison of the total number of the time compartments in which the rainfall was

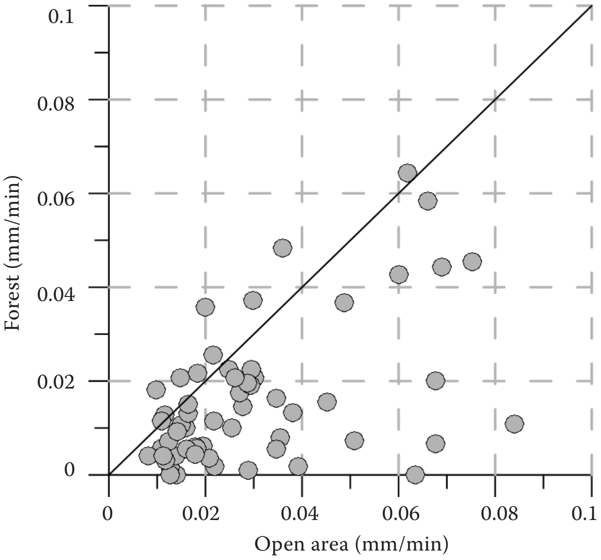

Figure 2. Mean rainfall intensities of the rainfall events in the open area and in the forest at site 1 (59 events)

Table 1. Saturated hydraulic conductivity of soils that occur in the Jalovecky Creek catchment calculated for different horizons; methods: 1 – Cosby, 2 – PLOTPF, 3 – Saxton, 4 – Puckett (in m/s)

| Soil type | Depth (cm) | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| **Rendzina** | 3–13 | 9.16E-07 | 1.86E-05 | 1.75E-06 | 7.31E-06 |
| | 15–25 | 7.42E-07 | 1.86E-05 | 1.15E-06 | 3.53E-06 |
| | 30–40 | 4.12E-07 | 3.76E-06 | 6.21E-07 | 5.61E-07 |
| | 50–60 | 4.93E-07 | 5.09E-06 | 7.41E-07 | 1.04E-06 |
| **Eutric Cambisol** | 5–15 | 1.41E-06 | 4.28E-05 | 1.31E-05 | 1.07E-04 |
| Slightly humic | 15–30 | 1.05E-06 | 2.37E-05 | 6.01E-06 | 4.42E-05 |
| Skeletal | 40–50 | 1.07E-06 | 3.28E-05 | 7.67E-06 | 5.94E-05 |
| (on gneiss bedrock) | 50–60 | 9.94E-07 | 2.31E-05 | 7.48E-06 | 5.81E-05 |
| **Dystric Cambisol** | 3–10 | 3.85E-07 | 2.42E-06 | 7.60E-07 | 8.50E-07 |
| Slightly humic | 15–20 | 3.60E-07 | 2.22E-06 | 9.42E-07 | 1.34E-06 |
| Skeletal (on gneiss bedrock) | 40–50 | 3.98E-07 | 7.48E-06 | 1.15E-06 | 2.89E-06 |
| **Dystric Cambisol** | 3–9 | 1.93E-07 | 8.29E-07 | 8.46E-07 | 7.39E-07 |
| Slightly humic | 15–25 | 1.45E-07 | 4.62E-07 | 6.57E-07 | 2.64E-07 |
| Skeletal | 35–45 | 1.66E-07 | 6.24E-07 | 6.00E-07 | 2.17E-07 |
| (on gneiss bedrock) | 60–70 | 1.63E-07 | 5.53E-07 | 5.22E-07 | 1.39E-07 |
| | 80–90 | 1.70E-07 | 1.67E-06 | 4.85E-07 | 9.17E-08 |
| **Ferro-Humic Podzol** | 15–25 | 1.26E-06 | 4.22E-05 | 9.12E-06 | 7.22E-05 |
| | 30–40 | 8.78E-07 | 1.87E-05 | 6.62E-06 | 5.06E-05 |
| (on gneiss bedrock) | 55–65 | 7.58E-07 | 1.28E-05 | 5.60E-06 | 4.08E-05 |
| | 70–80 | 8.69E-07 | 2.08E-05 | 7.31E-06 | 5.69E-05 |
| **Ferro-Humic Podzol** | 30–38 | 6.49E-07 | 8.12E-06 | 1.76E-06 | 6.64E-06 |
| | 45–50 | 4.98E-07 | 4.53E-06 | 1.23E-06 | 2.94E-06 |
| (on gneiss bedrock) | 85–90 | 5.54E-07 | 7.24E-06 | 5.45E-06 | 3.92E-05 |

recorded with those in which the rainfall intensities exceeded the chosen $K_S$ value shows that the conditions suitable for the generation of infiltration excess overland flow occurred very rarely. Depending on the $K_S$ values, they occurred for 0–10% of the rainfalls measured. Table 2 also shows the expected result that the conditions suitable for the generation of infiltration excess overland flow in the forest occurred less frequently than in the open area nearby.

Table 2. Numbers of 10-min rainfall compartments in the summer season of 2009 exceeding the $K_S$ values (expressed as mm/10 min) of the loamy-sand soil (ferro-humic podzol) calculated for different soil horizons

| Rain gauge (Figure 1) | Total No. of observed rain compartments (> 0.0 mm) | No. of rain compartments in which the rainfall intensity exceeded selected values of $K_S$ | | |
|---|---|---|---|---|
| | | $K_S$ = 3.18 Saxton (average soil) | $K_S$ = 5.47 Saxton (upper soil layer, max) | $K_S$ = 1.06 Saxton (upper soil layer, min) |
| 1 – open area | 986 | 19 | 5 | 94 |
| 1 – forest | 1035 | 12 | 7 | 68 |
| 2 | 681 | 6 | 1 | 37 |
| 3 | 948 | 9 | 1 | 90 |
| 4 | 682 | 7 | 1 | 62 |

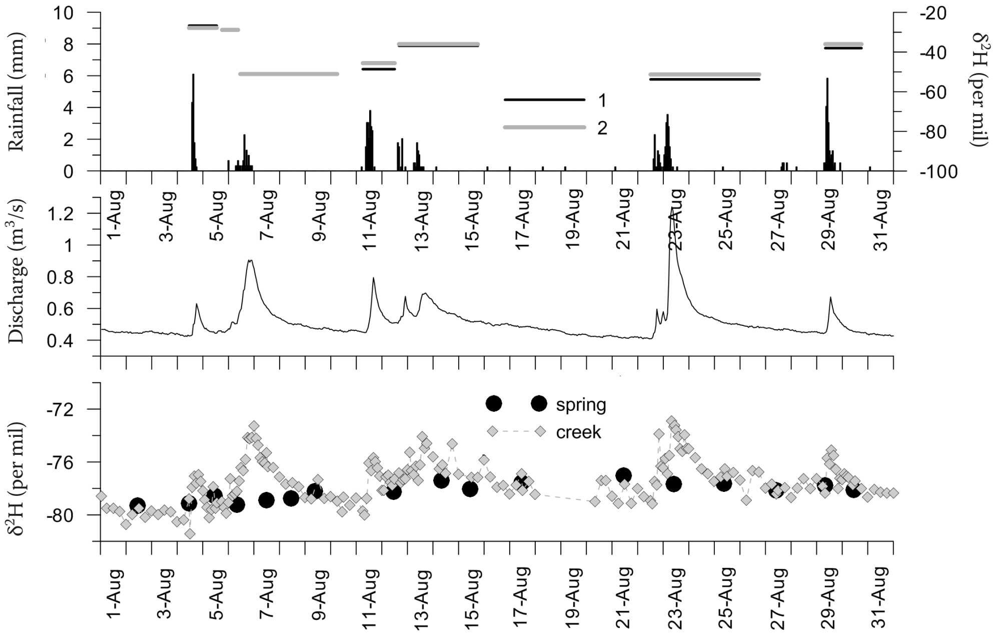

Figure 3. Precipitation, discharge and isotopic composition of water in August 2009; hourly data for the rainfall and discharge measurements; 1 – $\delta^2$H in precipitation ($\delta_e$) collected at the catchment mean elevation (site 1 in Figure 1), 2 – $\delta^2$H in precipitation ($\delta_e$) considering altitude gradient and enrichment in the forested part of the catchment

## Isotopic hydrograph separation and saturated areas

As already mentioned, August 2009 was relatively dry. Despite the occurrence of five small rainfall-runoff events, the catchment discharge was mostly under the long-term mean annual value of 0.7 m$^3$/s (Figure 3).

Figure 4 shows that the precipitation in the forest was isotopically heavier (enriched) than in the open area for all rainfall events measured. The enrichment found at 1500 m a.s.l. was smaller than the older data from altitude of 1100 indicated.

Values of $\delta_e$ and $\delta_p$ used in hydrograph separations are given in Table 3. The differences between the values estimated by the two different approaches described in the methodology were mostly relatively small. Table 3 also demonstrates great differences in the isotopic composition of different rainfalls. The range of the $\delta^2$H reached almost 20‰. All rainfalls were isotopically significantly heavier than the water in the Jalovecký Creek. The values of $\delta^2$H of water in the Jalovecký Creek during the events increased. $\delta^2$H of the spring did not react so fast and with such magnitude as that of the creek (Figure 3). This confirms

Table 3. Two sets of $\delta_e$ and $\delta_p$ ($^2$H) used in the separations; Set 1: $\delta_e$ – rainfall samples measured at the catchment mean altitude, $\delta_p$ – the Jalovecký Creek water sampled before the first event; Set 2: $\delta_e$ – altitude gradient in rainfall combined with the enrichment in the forest, $\delta_p$ – the spring water samples before the events (in ‰)

| Separated event | Set 1 | | Set 2 | |
|---|---|---|---|---|
| | $\delta_e$ | $\delta_p$ | $\delta_e$ | $\delta_p$ |
| 4 August | –26.7 | –79.8 | –27.8 | –79.3 |
| 5 August | –29.2 | –79.8 | –28.8 | –79.3 |
| 6 August | –51.1 | –79.8 | –51.1 | –79.3 |
| 11 August | –48.6 | –79.8 | –45.6 | –78.2 |
| 13 August | –36.9 | –79.8 | –36.0 | –78.2 |
| 22 August | –53.8 | –79.8 | –51.3 | –77.0 |
| 29 August | –38.0 | –79.8 | –36.0 | –77.8 |

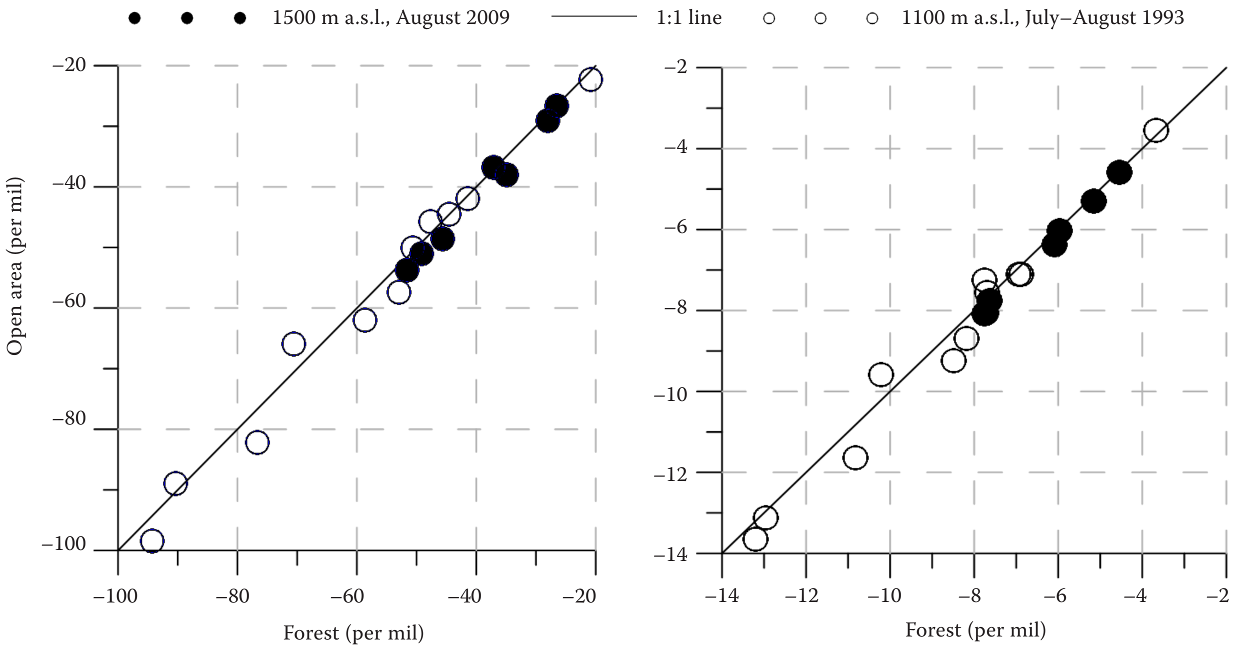

Figure 4. Isotopic composition of the rainfalls in the forest and in the open area for two locations in the Jalovecký Creek catchment; left – $\delta^2$H, right – $\delta^{18}$O

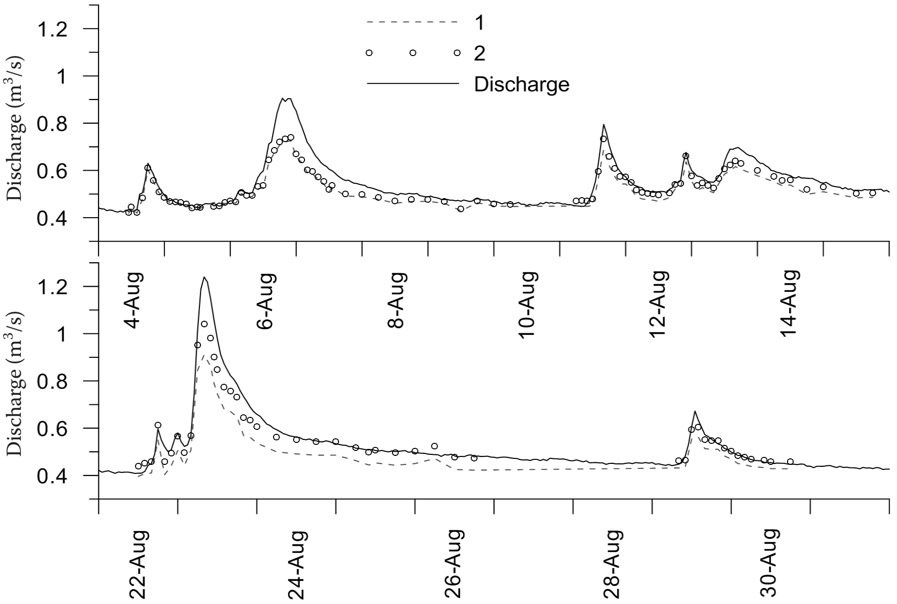

Figure 5. The Jalovecký Creek discharge at the catchment outlet and the contributions of the pre-event water (1, 2) to total discharge in August 2009; 1 – Set 1 from Table 3 for $\delta_e$ and $\delta_p$ was used in separations; 2 – Set 2 from Table 3 used in separations

that the spring is supplied with water of deeper circulation, although it is located on the bank of the Jalovecký Creek.

The separated contributions of the pre-event water to total catchment runoff with two sets of values for $\delta_e$ and $\delta_p$ are shown in Figure 5. If the few unrealistic points (for which the pre-event water contributions exceeded total runoff) are excluded, the pre-event water contributions vary between 73 and 100%. Minimum pre-event water contribution during the peakflows of the recorded small events was 73%. Areal extent of the saturated areas calculated from isotopic hydrograph separation varied between 2 and 13% of the catchment area.

## DISCUSSION

The short time rainfall measurements confirmed the known fact that the spatial distribution of the storm rainfall does not reflect only the altitude, but also the position of a rain gauge in the catchment. Thus, a relatively dense network of rain gauges has to be used to study the details of the rainfall-runoff relationships even in a relatively small mountain catchment.

The saturated hydraulic conductivities of the soils present in the studied catchment and calculated by different methods vary by one or two orders of magnitude. Therefore, several values of the $K_S$ given by the subjectively "best" method were used to estimate the frequency of possible infiltration-excess overland flow generation at different sites. The differences among the sites were small. It may be interesting to note that the highest frequency of the possible infiltration-excess overland flow occurrence was not calculated for the highest altitudes which generally receive the most rainfall but for the site situated at the catchment mean altitude. This fact reflects the soil properties at different sites.

The field measurements of the saturated hydraulic conductivity would provide a more reliable data for the analysis of the possibility of the infiltration excess overland flow occurrence. Bonell *et al.* (2010) used the measured values of $K_S$ together with the rainfall intensity-duration-frequency characteristics to infer the dominant stormflow pathways in different forests in India. However, it is known that the hydraulic properties of the soils and infiltration capacity have a significant spatial and even temporal variability of the infiltration capacity of soils (e.g.Tricker 1981; Greminger *et al.* 1985; Woolhiser *et al.* 1996; Corradini *et al.* 1997; Bonell *et al.* 2010). Other factors than soil properties, such as soil repellency, may be important in the infiltration excess overland flow generation in certain catchments (Miyata *et al.* 2010). On the other hand, obvious differences were identified (e.g. Price *et al.* 2010) in the physical characteristics of soils including $K_S$ depending on the land use. The field measurements of $K_S$ by means of the ring infiltrometers are limited by the small scale of the sampled area and by the difficulty in the selection of representative sample points in inaccessible, steep forests with trees, rocks, burrowing animals and tree-root holes (Sheridan *et al.* 2007). Descroix *et al.* (2007) recently presented a simple deterministic, API (antecedent precipitation index) based model to simulate the occurrence of infiltration or saturation excess overland flow in a catchment. Such a tool could help to assess the frequency of the overland flow occurrence as well.

The isotopic runoff separation has several sources of uncertainties, e.g. the spatially and temporally variable isotopic composition of rainfall or variable isotopic composition of the pre-event water. In this work, we considered spatial variability of the isotopic composition of rainfall taking into account the altitude effect and enrichment in the forest. The variability of isotopic composition during rainfall was not taken into account. We considered the variable isotopic composition of the pre-event water using the samples from the spring. Areal extent of the saturated areas generating the saturated-excess overland flow calculated for August 2009 was consistent with the previous results and modelling in the catchment (e.g. Holko & Lepistö 1997; Kostka & Holko 2001). The values obtained in this study are realistic taking into account the areal extent of the areas in the catchment which have a higher potential to become saturated, i.e. relatively flat bottoms of some valleys.

## CONCLUSIONS

The combined analysis of the short-term rainfall measurements, calculated saturated hydraulic conductivities, and isotopic hydrograph separations provided useful information on the probable frequencies of the infiltration excess and saturation excess overland flow generation in the studied catchment during the warm period of the year. It should be kept in mind that the assessment contains uncertainties. However, the results are consistent with the empirical knowledge of the catchment where the evidence of the occurrence of overland flow is only rarely observed. Ribolzi *et al.* (2007) note that the infiltration excess overland flow, which is a typical mechanism of the runoff generation in semi-arid regions, has often been disregarded in the studies performed in humid forested catchments. We believe it is important to continue with the effort focused on quantification of the occurrence of the overland flow in the catchment. Further validation in the studied catchment will be done by extended field measurements focused on the in situ measurements of $K_S$. The short term rainfall measurements provided additional useful information on the most frequent rainfall intensities in the studied catchment and on the network needed to study the details of the rainfall-runoff relationships in the mountain catchments. Smaller mean rainfall intensities of the individual rainfall events and generally isotopically heavier precipitation in the forest confirmed the results expected.

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Received for publication July 29, 2010
Accepted after corrections October 27, 2010

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