Steady infiltration rates estimated for a mountain forest catchment based on the distribution of plant species

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ABSTRACT: Among other important factors, vegetation cover strongly affects the hydrological processes in mountain catchments. In this paper, we present the results of field infiltration measurements at the location of various vegetation covers, together with an estimation of the infiltration characteristics of a small mountain forest catchment. Measured steady infiltration rate values were extrapolated on the basis of the dominant plant species distribution in the catchment. We determined which plant species are dominant, and infiltration tests were carried out where these species were located in selected sites in the catchment. The characteristic steady infiltration rates were averaged for each dominant vegetation species. The percentages of dominant plant species were determined for established points placed in a regular network throughout the basin. An extrapolation of the directly measured infiltration values to these established points was calculated using (1) percentages of the dominant plant species determined at these points, and (2) characteristic infiltration rates averaged for these species. An infiltration map was created from the infiltration values calculated for the established points.

Keywords: Bohemian Forest; experimental catchment; infiltration map; mountain Podzols; vegetation cover

Much hydrological research deals with the influence of vegetation cover on the infiltration, evaporation and water retention ability of the headwater areas of streams (Kvítek et al. 2001; Harden, Scruggs 2003; Zhang et al. 2011). Our study was carried out in the Šumava National Park, a border mountain range that is the primary water source for the major watercourses in southern Bohemia, Czech Republic. This area affects the water flow in lower-situated streams during extreme hydrometeorological situations. In recent decades, the original vegetation has been removed in large areas of mountain forests in southern Bohemia due to wind, air pollution, the bark beetle outbreak, and subsequent forest management practices. The mountain forest is now gradually being restored.

Infiltration is crucial in transforming rainfall to runoff, and for hydrological processes in the soil. Knowledge of the rainfall-runoff process of forest mountain catchments and of the influence of changes in vegetation cover (e.g. deforestation) on this process is important for assessing the hydrological regime of these areas (Germer et al. 2009). It is difficult to determine representative infiltration values in areas with heterogeneous soils, due to their temporal and spatial variability. It is very important to have detailed hydrological, geological, hydropedological, and vegetation cover information about the catchment in order to make a correct choice of measurement sites, and to make a correct interpretation of the measured values (Kutílek, Nielsen 1994).

Together with other factors, e.g. soil properties, position on the slope, and geological bedrock, vegetation has a significant influence on the infiltration process. However, the influence of different plant species is not fully understood, especially in the headwater areas of streams (Zhang et al.

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2011). Certain plant species prefer specific soil and moisture conditions. The relation between soil conditions and plants is mutual and dynamic. The root system of plants influences the soil properties (structure, porosity, hydraulic conductivity, soil water content), and the soil properties influence the occurrence of certain plant species (Stothoff et al. 1999; Solon et al. 2007; Li et al. 2008). Forest vegetation creates root macropores in the zone near to the soil surface. These macropores in the topmost layer of the soil in humid mountain forest regions increase the infiltration rates and facilitate downslope drainage (Harden, Scruggs 2003).

One or two concentric circular cylinders are generally used for measuring infiltration (Hillel 1998; Dingman 2002). The well permeameter is another method for measuring infiltration in boreholes (Kuráž 1996; Reynolds 2008). The Guelph permeameter, an effective modification of the well permeameter, was introduced by Reynolds and Elrick (1985). The method using this device is recommended for measuring field saturated hydraulic conductivity (McKenzie, Cresswell 2008). A more detailed description of infiltration measurement methods was given by Dirksen (1999) and by Jaramillo (2000).

Infiltration data is an essential input into physically-based hydrological models. Direct infiltration measurements lead to better estimations of the infiltration parameters for catchments. This improves the quality of the models. This paper presents an estimation of the infiltration characteristics for a small mountain catchment that is covered by an emerging forest (15 years after a bark beetle outbreak). An extrapolation of infiltration characteristics from direct measurements to the entire catchment is based on the vegetation cover distribution. The first objective of our research was to obtain data from direct measurements of the field infiltration into the podzolic soil. The second objective was to estimate characteristic infiltration values based on field measurements for each of the dominant plant species. The third objective was to extrapolate these infiltration values based on the spatial distribution of the dominant plant species, and then to create a vector infiltration map.

MATERIAL AND METHODS

Study area

Infiltration tests were carried out in the Modrava 2 experimental catchment, where hydrological monitoring has been performed for more than ten years. This catchment was also partly described by Pavlásek et al. (2009, 2010) and by Jačka and Pavlásek (2010).

The catchment is situated in the central part of Šumava National Park, near the border with Germany, approximately 7 km southwest of the village of Kvilda. The highest point is the summit of Malá Mokrůvka Mountain (1,330 m a.s.l.). The lowest point is the outlet of the catchment (1,188 m a.s.l.). Thomson weir is located at this point to measure the flow rate of the Mokrůvka stream, which drains the catchment. The catchment area is 0.17 km^2. The fall line length is 0.745 km, and the average slope gradient is 21%.

The original 160-year-old spruce forest (*Picea abies*) which had formerly covered the catchment was removed after the bark beetle outbreak in 1994–1995. Traces of forest logging (tree stumps, remnants of dead wood, forest logging paths, and soil compaction caused by the forestry machinery) are still visible. These traces influence the hydrological regime in the catchment and the rainfall-runoff process. Nowadays, the catchment is covered with restored young trees aged about 10–15 years. Primarily Norway spruce (*Picea abies*) was planted. Maples (*Acer pseudoplatanus*) and European mountain ash (*Sorbus aucuparia*) were also used in the lower-lying part of the catchment.

Percentages of dominant plant species (covering more than 5% of the catchment area) were determined by Jindrová (2011), as follows: *Calamagrostis villosa* 32.1%, *Picea abies* 25.6%, *Vaccinium myrtillus* 19.5%, *Athyrium distentifolium* 7.0%, *Avenella flexuosa* 6.1% and *Luzula sylvatica* 6.1%. The rest of the surface (3.6%) includes areas with no vegetation (e.g. dead trees, stumps, debris, and sites of frequent puddles) and the soil surface covered with other plant species.

The predominant soil type is Podzol, subtype Haplic Podzol. The vertical heights of the soil horizons measured gradually from the soil surface downwards are as follows: overlying organic soil horizon O approximately 5 cm; barely distinguishable black humus horizon Ah 1–5 cm; bleached, ash-like layer of eluvial horizon E in the range 8–15 cm; spodic Bhs horizon rich in sesquioxides, chelates and humic substances translocated from the upper soil horizon – approximately 15 cm; Bs horizon rich in sesquioxides and chelates – approx. 25 cm. Horizon E is loamy-sand soil containing about 1% clay and 25% silt. Horizons Bhs and Bs contain approximately 7% clay and 32% silt (textural class sandy-loam). The mean porosity values estimated for the soil horizons are as follows: horizon O 85%, E 49 %, Bhs about 47%, Bs 46%.

Measurement sites

Due to (1) time-consuming measurements and (2) the need to perform a large number of infiltration tests, experiments were not performed in the whole area of the catchment. The infiltration experiments were made at three selected sites, which represented the characteristic properties of the catchment (Fig. 1). The factors for site selection were as follows: position on the slope, elevation, vegetation cover, hydropedological and hydrogeological characteristics, and mutual distance of the sites in the catchment.

The first site was located on the fluvial and deluvial quaternary gravel-sandy deposits in the lowest part of the catchment, near the outlet. The soil profile of site one was the deepest (65 cm), and the soil horizons were less distinct than at sites two and three. Site one was covered mainly with *Vaccinium myrtillus* (about 35% of the surface), *Picea abies* (20%), and *Calamagrostis villosa* (20%). The percentages of other plant species were as follows: *Avenella flexuosa* (5% of the surface), *Luzula sylvatica* (5%), *Athyrium distentifolium* (5%), and other soil cover (*Sphagnum* spp., *Polytrichum* spp., *Betula* spp., *Salix* spp. about 10%).

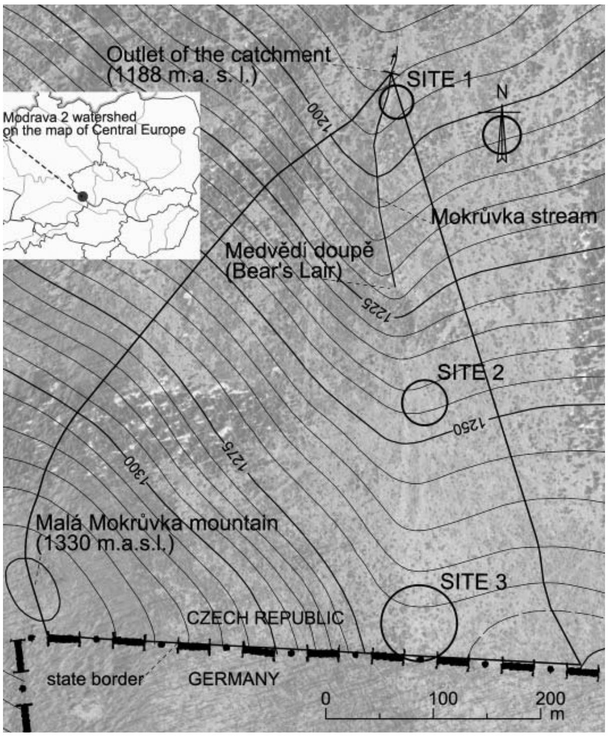

Fig. 1. Location of the measurement sites in the Modrava 2 experimental catchment

The second site was situated on a slightly sloping hillside in the middle part of the slope. The geological bedrock was Carboniferous granite. The depth of the soil profile was approx. 55 cm and the podzolic horizons were more distinct than at site one. Site two was covered with *Calamagrostis villosa* (65% of the surface), *Luzula sylvatica* (15%), *Picea abies* (10%), *Avenella flexuosa* (5%), *Vaccinium myrtillus* (0%), *Athyrium distentifolium* (0%), and other soil covers (mainly *Polytrichum* spp. 5%).

The third highest-placed site was established in the saddle, near the border with Germany. The bedrock consisted of weathered metamorphic rocks (sillimanite, migmatite, paragneiss) and granites. The depth of the soil profile was 50 cm. The soil layers were distinct. Site three was covered mainly with *Calamagrostis villosa* (55%), *Picea abies* (20%), *Avenella flexuosa* (10%), *Vaccinium myrtillus* (5%), *Luzula sylvatica* (3%), *Athyrium distentifolium* (3%), and other soil covers (4%).

Field measurements of infiltration

The infiltration tests were always performed at least two days after a rainfall. The initial soil water content was determined from soil samples (100 cm^3) that were collected before the infiltration experiment. Other soil samples were collected to measure selected soil-water characteristics (soil water content after the experiment, texture, porosity, bulk density, and saturated hydraulic conductivity) at the measurement sites. The infiltration tests were performed using two devices – a single ring infiltrometer and a Guelph permeameter. These two methods were combined to increase the number of infiltration tests and reduce time-consuming measurements. The infiltration tests performed at each site were planned to be made randomly at the location of the dominant plant species (with the exception of *Picea abies* – see below).

A thin-walled (2 mm) steel ring with one sharpened side was used for the single ring infiltration experiment. The ring was 30 cm in diameter and 25 cm in length. The ring was manually pushed into the vegetation cover. A grass sod was cut through with a knife around the cylinder. This was done vertically, without disturbing the area below the cylinder. Then the ring was hammered into the soil to a depth of 10–15 cm. A special cast-iron cross was used to facilitate inserting the ring. The inside surface of the ring was disturbed as little as possible.

Where necessary, the vegetation was sometimes carefully cut with scissors to enable the water level to be read. Spikes hung from the top of the infiltrometer were used to control the water level inside the single ring. The surface inside the single ring was flooded with water to a level of about 3 cm. During the early stages of infiltration (the period with the highest infiltration rate), a system of spikes was used. A known volume of water was refilled after the water drew back from the reference spike. The time was recorded. We continued to supply a known volume of water and to measure the time until a quasi-steady infiltration rate was reached. This took about 1–2 hours. The steady infiltration rate was calculated using the arithmetic mean of the last three measured values.

A Guelph permeameter was used to measure the field saturated hydraulic conductivity K_{fs} in shallow boreholes, ca 20 cm in depth with a water level of 16.5 cm. The main root system of the plants was assumed to be within this measurement depth. The borehole was 7 cm in diameter. The steady state infiltration rate through the walls and the bottom of the borehole was measured. Laplace-Gardner analysis (Reynolds, Elrick 1985) was used to calculate K_{fs}.

We made use of the idea that the steady-state infiltration rate, measured by the single ring (with a small 3 cm pressure head, diameters of 28 and 30 cm, depth of insertion 10–15 cm, and in sandy loam soil conditions) was approximately equal to K_{fs}. The error was considered negligible in comparison with the soil heterogeneity error. Single ring and Guelph permeameter methods were also compared using data measured in the third site. In this specific case (soil properties, depths of measurement, evaluation procedure of measuring), *t*-test indicates that the true difference in means (obtained by the two used methods) is equal to zero at the 0.05 significance level. Kolmogorov-Smirnov test was applied to test the null hypothesis that two datasets (obtained by the Guelph permeameter and the single ring in the third site) originate in the same statistical population. The null hypothesis was accepted by this test at the 0.05 significance level.

Infiltration experiments using the single ring and the Guelph permeameter were planned to be made mostly at the location of one of the five dominant plant species: *Vaccinium myrtillus, Avenella flexuosa, Luzula sylvatica, Calamagrostis villosa* and *Athyrium distentifolium.* No measurement was performed on the surface covered with spruce (*Picea abies*). The dense root system and low branches of the young trees made it impossible to insert the infiltration ring or to drill a borehole for the Guelph permeameter. The infiltration experiments were carried out at the end of July, in August, and at the beginning of September. Thus, the measurements were made during the growing season, in the period with the highest vegetation activity and evapotranspiration.

Evaluation and extrapolation of the measured infiltration data

The experiments (data of both methods), which were made at the location of the dominant plant species were evaluated as a single data set. Further, characteristic steady infiltration rate values were calculated for each of the five dominant vegetation species (*Vaccinium myrtillus, Avenella flexuosa, Luzula sylvatica, Calamagrostis villosa* and *Athyrium distentifolium*). The characteristic infiltration value for the plant species was computed by the geometric mean, using all single ring and Guelph permeameter data measured at the location of the species. A characteristic infiltration value for *Picea abies* was computed by the arithmetic mean from the characteristic infiltration rates calculated for the five dominant vegetation species. For the phytocoenological survey (Jindrová 2011), a regular square grid of 115 mapping points was established in the catchment. The points were 50 m apart. There were a total of 67 points inside the catchment area. The rest of the points were near to the catchment border. The percentages of dominant vegetation species were determined at all points in a circle 10 m in radius. The centre of the circle was placed at the mapping point. For each point, the infiltration rate was calculated by the weighted average. The weightings were percentages of plant species. The input infiltration data were the characteristic infiltration rates that were calculated for each of the dominant vegetation species. A vector infiltration map was created from the established mapping points, using the Create Thiessen polygon function in ESRI ArcGis Desktop 9.3. This vector map consisting of squares (with 50 m sides) was created to represent the infiltration values of points located in the centre of these squares.

RESULTS

Measured data, not taking vegetation cover into consideration

All of the infiltration tests were made at three sites (Fig. 1) in the summers of 2008, 2009, 2010

Table 1. Statistical characteristics of measured data and infiltration values at the mapping points

Type of raster interpolation	Measured data	Characteristics of mapping points	
Arithmetic mean [(m·s^{-1}) × 10^{-5}]	3.643	1.593	1.572
Geometric mean [(m·s^{-1}) × 10^{-5}]	0.903	1.514	1.502
Median [(m·s^{-1}) × 10^{-5}]	0.813	1.506	1.481
Standard deviation [(m·s^{-1}) × 10^{-5}]	7.665	0.528	0.498
Coefficient of variation (%)	210	33	32
Minimum [(m·s^{-1}) × 10^{-5}]	0.049	0.788	0.788
Maximum [(m·s^{-1}) × 10^{-5}]	34.124	3.132	3.302
Percentiles 0.25 [(m·s^{-1}) × 10^{-5}]	0.323	1.256	1.252
Percentiles 0.75 [(m·s^{-1}) × 10^{-5}]	2.272	1.876	1.82
Kurtorsis	6.737	0.714	1.455
Skewness	2.794	0.91	1.075
No. of experiments or points	80	67[a]	115[b]

[a]mapping points inside the catchment, [b]all mapping points

and 2011. A total of 80 experiments were evaluated. The descriptive statistics of the estimated steady infiltration rates are presented in Table 1. The initial average volumetric soil water content value was 50% in the two uppermost horizons (organic soil horizon O and black humus horizon Ah) and 40% in the ash-like layer of eluvial horizon E. The Shapiro-Wilk normality test was used to compare the decadic logarithms of the measured data with the relevant normal distribution. The calculated Shapiro-Wilk test values were w = 0.967 and P = 0.036. The hypothesis of the normal distribution of the logarithms of the measured infiltration data was rejected by the Shapiro-Wilk test at the 0.05 significance level.

Infiltration rates for each dominant plant species

All of the evaluated measurements (80) were made at the location of five dominant plant species (*Vaccinium myrtillus, Avenella flexuosa, Luzula sylvatica, Calamagrostis villosa* and *Athyrium distentifolium*). The steady infiltration rates measured at the locations of these particular species are graphically depicted by the box plots in Fig. 2. Infiltration values, which are positioned more than one-times the interquartile distance (Fig. 2), were defined to be outliers. These outliers introduce strong heterogeneity into the measured data and are probably caused by another effect(s) than vegetation cover (e.g. preferential flow paths caused by soil fauna). All values (including outliers) were used for the creation of final vector maps. The outliers were included (using appropriate means, Table 2) for the final quantification because they probably occur in the whole catchment area. For the comparison (using descriptive and test statistics) of the different vegetation influence on the infiltration, the outliers were not used. The descriptive statistics of the

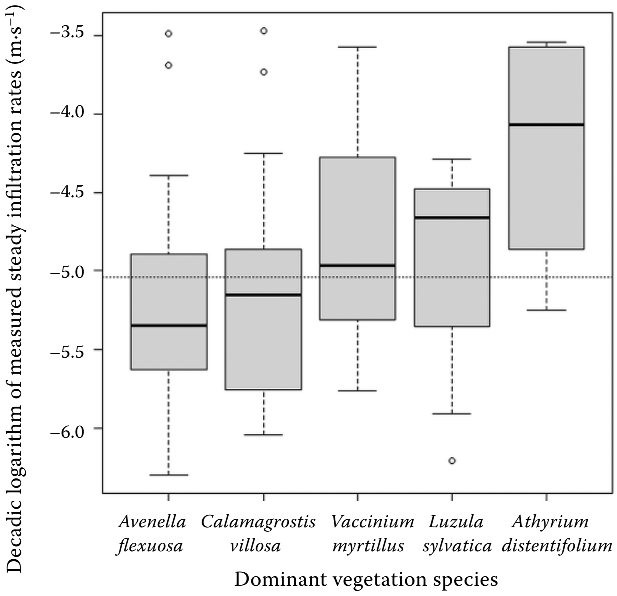

Fig. 2. Box plots (sample minimum, first quartile, median, third quartile, maximum and outliers) of the steady infiltration rates measured at the locations of different plant species; dotted line shows the arithmetic mean of all logarithmic values

Table 2. Steady infiltration rates measured at the locations of the dominant plant species

Statistical parameters	*Avenella flexuosa*	*Calamagrostis villosa*	*Vaccinium myrtillus*	*Luzula sylvatica*	*Athyrium distentifolium*
Geometric mean[a] [$(m \cdot s^{-1}) \times 10^{-5}$]	0.612	0.686	1.387	1.114	5.929
Arithmetic mean[b] [$(m \cdot s^{-1}) \times 10^{-5}$]	0.813	0.927	4.332	2.368	12.664
Geometric mean[b] [$(m \cdot s^{-1}) \times 10^{-5}$]	0.464	0.494	1.387	1.490	5.922
Median[b] [$(m \cdot s^{-1}) \times 10^{-5}$]	0.424	0.626	1.121	2.395	9.175
Standard deviation[b] [$(m \cdot s^{-1}) \times 10^{-5}$]	0.929	1.222	8.112	1.753	12.532
Coefficient of variation[b] (%)	114	132	187	74	99
Minimum[b] [$(m \cdot s^{-1}) \times 10^{-5}$]	0.050	0.091	0.172	0.123	0.561
Maximum[b] [$(m \cdot s^{-1}) \times 10^{-5}$)]	4.020	5.620	26.700	5.180	28.900
Percentiles 0.25[b] [$(m \cdot s^{-1}) \times 10^{-5}$]	0.232	0.165	0.494	0.768	2.466
Percentiles 0.75[b] [$(m \cdot s^{-1}) \times 10^{-5}$]	1.044	1.060	4.463	3.438	23.294
No. of experiments	29	24	10	11	6
No. of outliers	2	2	0	1	0

[a]outliers were included, these means were used for the infiltration map creation, [b]outliers were not included

infiltration characteristics calculated for each of the plant species are given in Table 2. The lowest median, the lowest geometric mean, the lowest minimum, the lowest maximum, and the lowest third quartile were evaluated for *Avenella flexuosa*. Lower steady infiltration rate values (very similar to those for *Avenella*) were also evaluated for *Calamagrostis villosa*. The second highest arithmetic mean was measured at the location of *Vaccinium myrtillus.* The second highest median and geometric mean were evaluated for *Luzula sylvatica*. The geometric mean, median and also the first and third quartiles measured for *Luzula* were similar to those for *Vaccinium.* The significantly highest values (means, quartiles, median) were measured at the location of the fern *Athyrium distentifolium*.

The measured steady infiltration rates for each of the dominant plant species were tested by the Shapiro-Wilk normality test. The null hypothesis – that the measured infiltration data is normally distributed – was accepted for the measurements made at the locations of *Luzula sylvatica* and *Athyrium distentifolium* at the 0.05 significance level. The coefficients of variation measured for these species were lower than for the other three species (Table 2). The null hypothesis was rejected for the measurements made at the locations of *Vaccinium myrtillus, Avenella flexuosa, and Calamagrostis villosa* by the Shapiro-Wilk test at the 0.05 significance level. The decadic logarithms of the measured infiltration rates for each of the five plant species were tested again by the Shapiro-Wilk test. The null hypothesis (that the measured logarithms of the steady infiltration rates are from the normally distributed population) was accepted at the alpha 0.05 significance level for the measurements made at the location of each dominant plant species.

The one-way analysis of variance (ANOVA) was performed on the decadic logarithms. The aim of this analysis was to decide whether the difference in the sample means of each plant species is indicative of a difference in the population means of these species, or whether it is caused by a sampling variation. The results of the one-way ANOVA test (not assuming equal variances, $F = 4.920$, num df = 4.000, denom df = 20.303, $P = 0.006$) indicate that the differences in the mean values are not caused by the sampling variation at a significance level 0.05. *T*-tests (Welch Two Sample *t*-test) were used for comparisons of means (10 pair comparisons) of 5 datasets, which were measured at the location of 5 dominant plant species. These *t*-tests were done on the decadic logarithms. Differences in the mean values were statistically significant at the 0.05 significance level for the following pairs: *Avenella* vs. *Athyrium* ($t = -3.665$, df = 6.142, $P = 0.010$), *Calamagrostis* vs. *Athyrium* ($t = -3.518$, df = 6.523, $P = 0.011$), *Luzula* vs. *Avenella* ($t = 2.606$, df = 14.993, $P = 0.019$), *Luzula* vs. *Calamagrostis* ($t = 2.375$, df = 16.750, $P = 0.030$). *T*-tests suggested differences in the mean values (but not statistically significant at the 0.05 significance level) for the following pairs: *Vaccinium* vs. *Avenella* ($t = 2.055$, df = 12.817, $P = 0.061$), *Vaccinium* vs. *Calamagrostis* ($t = 1.886$, df = 14.020, $P = 0.0803$).

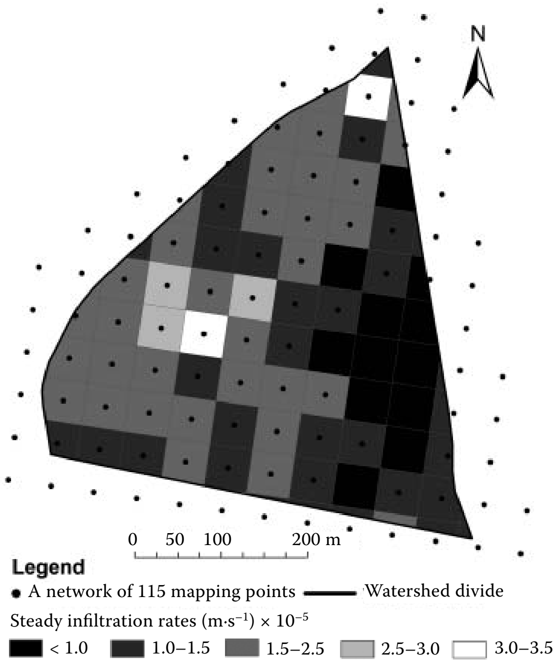

Fig. 3. Infiltration map consisting of squares with the infiltration values of points inside of them

Infiltration rates extrapolated for the mapping points

Infiltration rates were calculated for 115 points (the points with information about the percentages of the dominant plant species). The regular network of points, the infiltration values at the points and the watershed divide are shown in Fig. 3. Descriptive statistics of characteristic infiltration values at these points are given in Table 1. The logarithms of the steady infiltration rates were tested by the Shapiro-Wilk test. The null hypothesis (that the logarithms of the calculated infiltration values came from a normally distributed population) was accepted at the 0.05 significance level (w = 0.987, P = 0.330). There were a total of 67 points inside the catchment (see Fig. 3). The descriptive statistics of the infiltration rates calculated for these points are presented in Table 1. The arithmetic mean of the calculated infiltration rates for the points inside the catchment was 1.59×10^{-5} m·s^{-1} and the geometric mean was 1.51×10^{-5} m·s^{-1}.

DISCUSSION

An original method for estimating infiltration for the entire catchment

It is very difficult, time-consuming and sometimes impracticable to determine with precision the infiltration characteristics for the entire mountain catchment. A very large number of field measurements needs to be made in these specific conditions (e.g. hundreds of infiltration tests in our catchment), because the soil properties are very heterogeneous and the measured infiltration rates vary in time and space. The idea of our research is to extrapolate a smaller number of field infiltration tests to the larger area of the entire experimental catchment. The results are estimated steady infiltration rate values distributed all over the catchment. The extrapolation is based on the distribution of the vegetation cover. Vegetation is a readily determinable and easily detectable important factor influencing the infiltration process (Solon et al. 2007; Zhang et al. 2011). Soil properties and bedrock are other important factors that are in close relation with the vegetation cover.

It is obvious that this estimation of the infiltration rates has deficiencies, and is not entirely accurate. A disadvantage of using only the vegetation factor for the extrapolation may be a lack of directly measured values for the extrapolated areas to verify the quality of the extrapolated data. Other disadvantages include variable demands of a single plant species on soil properties; this means that the influence of other factors (geological bedrock, slope position, soil texture and structure) on infiltration is not exactly quantified by this original method.

On the other hand, this estimate is fast and efficient, and it can provide a more accurate infiltration input for hydrological models than the input that is usually provided. Nowadays, estimations of the saturated hydraulic conductivity (or the steady infiltration rates) of catchments based only on soil texture are often used as an input for hydrological models (Schaake et al. 2006). Using remote sensing to determine the vegetation cover and information about the characteristic infiltration rates of plant species can improve the estimation of infiltration characteristics for large areas with the same dominant plant species and with similar soil and climatic conditions.

Results of field measurements of steady infiltration rates

Vegetation activity and thus the influence of vegetation on infiltration vary during the year. The maximum effect of vegetation on infiltration was expected to be in the middle of the growing season. The infiltration experiments were therefore made in this part of the year, and the measured data is valid only for this period.

The field measurements had a high coefficient of variation 210%. The probable reasons for the high coefficient of variation are high soil heterogeneity, rocks, dead wood, and roots in the soil profile of Podzols. These factors increase the preferential flow. A very high coefficient of variation (approx. 150%) and log-normal distribution of the dynamic hydraulic properties are the standard result (Pennock et al. 2008). Research similar to that presented in our study was performed by Tachecí (2002), who used a single ring to measure the infiltration of Dystric Cambisol in the small Uhlířská forest catchment in the Jizerské hory Mountains. This ring, 36 cm in diameter, was inserted circa 15 cm into the soil and flooded to a depth of approx. 10 cm. More than 100 infiltration tests were performed. The coefficient of variation was 126%, and the arithmetic mean of the steady infiltration rates was 1.7×10^{-4} m·s^{-1}.

Estimated infiltration rates for each dominant plant species

Measured steady infiltration rates vary with changes in vegetation cover. Although the number of infiltration tests was not large enough to give precise estimates for each plant species, we can observe some trends. The measured steady infiltration rates for the five dominant species are very different in some cases (see Fig. 2, and Table 2). The steady state infiltration rates measured for *Athyrium distentifolium* are much higher than for the other plant species. This may be due to the characteristically dense root system of *Athyrium distentifolium*, which significantly changes the porosity of the upper soil layer. Another potential reason may be the preference of this plant for higher soil permeability. The same factors may also underlie the higher infiltration rates measured for *Vaccinium myrtillus* and *Luzula sylvatica*. Areas dominated by *Avenella flexuosa* and *Calamagrostis villosa* can be predicted to have lower infiltration rates. In order to reach an exact conclusion, these hypotheses need to be tested using a larger number of measurements in different study areas with similar climatic and soil conditions.

CONCLUSIONS

This case study has presented results of *in situ* infiltration measurements of the specific conditions of the re-emerging mountain forest and podzolic soils. Infiltration data can improve our knowledge of rainfall-runoff processes from this hydrologically important area. Two measuring methods were combined (a single ring infiltrometer and a Guelph permeameter) and the results are presented in Table 1. The range of measured values and coefficients of variations were high due to the heterogeneity of the soil, the extreme soil layering and the changing soil cover. An important factor that influenced the steady infiltration rates in the upper soil layer was the vegetation cover.

Characteristic infiltration rates were calculated from the measurements taken at the location of each dominant plant species (see Table 2). The highest arithmetic and geometric means were measured for *Athyrium distentifolium*, and the higher ones were recorded for *Vaccinium myrtillus* and *Luzula sylvatica*. This may have been caused (1) by the characteristics of the root systems of these plants, which influence the soil porosity in the top layer, or (2) by their specific habitat requirements (a preference for higher soil permeability). The lowest means and median were measured for *Avenella flexuosa*. Slightly higher mean and median were measured for *Calamagrostis villosa*, although they were approximately the same.

An original method for infiltration extrapolation was shown in this paper. An estimation of the steady infiltration rate was made for the entire experimental catchment, using (1) characteristic infiltration rates measured where certain plant species are dominant, and (2) the percentages of dominant plant species determined at established mapping points. This extrapolation, based on easily identifiable vegetation cover, led to estimations of the infiltration rates for these points. Infiltration map, which was created using infiltration values of the points, is recommended for a subsequent spatially distributed hydrological model.

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