DAILY BASEFLOW VARIATIONS AND FOREST EVAPOTRANSPIRATION

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Abstract

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Diurnal variation of baseflow from a small partially waterlogged experimental forest catchment (32.6 ha) in the Orlické hory Mts (NE Bohemia), covered by a young Norway spruce forest (82%) with local admixture of broadleaves and silver fir, and a mature Norway spruce and European beech forest (18%), was investigated during the rainless periods in summer hydrological half year 1997 and 1998. Assessment of scientific knowledge in relation to natural conditions of our mountains resulted in a hypothesis that for a rainless period the main cause of streamflow decrease at daytime against night time consists in forest evapotranspiration (transpiration of vegetation cover and evaporation from soil). The computed decrease of discharge related to the catchment area directly connected with the drainage network (natural watercourses and open drain ditches) of total length equalled to 1 180 m responded to the evapotranspiration on the estimated area 2.12 ha; the discharge decrease ranging from 22 000 to 87 000 l with mean value 45 000 l per day resulted in the evapotranspiration ranging from 1.1 to 4.1 mm with mean value 2.1 mm per day. The values agree with the data of other authors who have assessed evapotranspiration of spruce and beech forests by different methods in similar mountain conditions. In cold and humid mountain regions of the Czech Republic, where the evapotranspiration is restricted by more heat balance than water supply available to evapotranspiration, the method in question could be for rainless periods generalized.

Key words: mountain forest, experimental catchment, drainage, diurnal variations, evapotranspiration, Czech Republic

Introduction

Within the soil water regime observation of the partially waterlogged mountain catchment U Dvou louček (near the village Říčky in the Orlické hory Mts, Czech Republic), after doing the drainage in support of the forest stand regeneration and forest plantation growing out, we recorded diurnal streamflow variation during the precipitation free period. The decline of the streamflow in the daytime against that in the night time, without influence of precipitation, is the expression of diurnal fluctuation of baseflow from the catchment. We have tried to explain the cause of the fluctuation by analyzing the results of conducted measurements.

Analysis of the problems

We firstly touched on changes of baseflow during day and night time in our paper in Ekológia (Bratislava) (Šach et al., 2000); on Fig. 4 we presented hydrograph of discharge waves in August 1997 and noted the small waves on recession leg of the hydrograph probably detecting the evapotranspiration of the waterlogged part of the catchment; therein we also promised to give special paper devoted to the interesting problem.

In literature the diurnal variation of streamflow during precipitation free period is not mentioned so often. The analysis of its causes was performed by Constantz et al. (1994) and Constantz (1998). He substantiated the fluctuation by increasing of water temperature in a watercourse during daytime against night time and consequently greater infiltration into a streambed. Ronan et al. (1998) contemplated the relation between streamflow decrease in daytime and associated evapotranspiration of riparian vegetation, nevertheless, as the main factor of that streamflow decrease during daytime they considered temperature changes of water infiltrating into a streambed. We believe the theory can be accepted only in arid regions with conditions similar to those in the Middle West of the United States, where Constantz et al. (1994, 1998) and Ronan et al. (1998) carried out their investigations. Under those conditions the evaporation from water surface and infiltration of water into streambeds represent the main loss factors. In humid regions, where streams predominantly drain landscape, the theory by Kobayashi et al. (1990, 1995) and Bren (1997) better corresponds with local natural conditions. They consider the evapotranspiration of riparian vegetation to be the main cause of diurnal streamflow fluctuation.

In accordance with that knowledge, the changes of baseflow during day and night time in conditions of the catchment U Dvou louček were most likely caused by loss of soil water from saturated horizons of waterlogged and drained part of the catchment and from saturated horizons of natural watercourse surroundings connected directly hydraulically with streambed. The water loss was, in all likelihood, induced by total evaporation comprising transpiration of tree species and ground vegetation, evaporation from soil, interception evaporation from vegetation cover and evaporation from water surface of streams. The interception practically did not occur in precipitation free period and evaporation from water surface of streams was negligible in relation to total evaporation from the catchment area. To express water loss from the catchment, just only transpiration of trees and ground vegetation and evaporation from soil, i.e. evapotranspiration, were substantial. The deduction resulted from known increased soil water uptake by fine roots of trees on daytime transpiration, when concurrently under the drought period the evaporation from soil and transpiration of ground vegetation raised. We submitted the hypothesis on the basis of recording of outflow decrease at daytime against night time, when at night processes of total evaporation were not running so intensively, and on the basis of stream discharge analyses performed on the catchment U Dvou louček in the Orlické hory Mts.

Material and methods

Experimental catchment U Dvou louček

The U Dvou louček experimental catchment was established for the purpose of studying the problems of draining a waterlogged forested catchment situated on a mountain slope. The small forested catchment U Dvou louček is located in the uppermost part of the Orlické hory Mts. The position of the catchment is determined by geographical coordinates l6°30'56'' E and 50°l3'16'' N. The catchment is situated at an altitude of 880–950 m; the mean altitude according to a hypsographic curve is 922 m.

The catchment is fan-shaped (substitute figure being a parabola with the side B length 820 m), form coefficient is 1.16, catchment divide length is 2 290 m (coefficient of the catchment divide division 1.13) and talweg length is 530 m. The area of the catchment amounts to 32.6 ha. The area exhibits variable slope, viz. in the lower part 7.5°, in the middle part 8.5° and in the upper part 4.3°. The mean slope calculated from the course of contours is 6.4°. The talweg inclination is 5.4°. The SW catchment aspect changes in border parts to the SE and W aspects. A watercourse draining the catchment is formed by two branches. The right branch exhibiting 5.9° inclination is 340 m long while the left branch having 5.3° inclination is 300 m long. One quarter of the catchment area is affected by high groundwater table (flowing water and spring area). Permanent waterlogging occurs on 5.5 ha, temporary waterlogging in the summer half-year does not exceed the area of 5 ha. Except for the period of soil profile waterlogging, volume soil moisture ranges from 30 to 60%. In the winter half-year, soil profile is saturated by water to the field moisture capacity in the whole catchment. The area of the full-grown beech/spruce stand (mean age 80 years) was 6.8 ha in 1991 (21% of the area) and till the year 1995 decreased to 5.7 ha (17.5%) due to the further disintegration of spruce ecosystems. The remaining area of the catchment is a clear-cut area resulted from air pollution salvage felling (the catchment is situated in the air pollution danger zone A) with a Norway spruce young plantation of various age (max. 15 years old). Road density in the catchment amounts to 62 $m.ha^{-1}$ and it is formed by skidding and hauling roads.

In the U Dvou louček catchment, hydrological and silvicultural research programmes are conducted. The hydrological programme includes catchment calibration in hydrological years 1991/92–1995/96 including recording hydropedological characteristics, manual implementation of the ecological draining measure in summer 1996 and the study of the effects of draining on further hydrology and hydropedology of the catchment. Draining measures aimed at the restoration of functions of the existing drainage system and the interception of runoff from spring areas and areas with insufficient drainage were carried out on the area larger than 2 ha. The length of drainage ditches reached about 500 m. The silvicultural research programme follows up the implemented drainage. It deals with the improvement of the survival and growth of established spruce young plantations and increasing their biodiversity and ecological stability. In part of the drained area protected by fencing of an area of about 1 ha with various degrees of soil profile moisture, beech, sycamore maple and silver fir are interplanted into the spruce plantation and on unforested places since 1997. Various types of mound and ridge planting and amelioration using natural materials (basic rock meals) were applied.

To obtain input data, precipitation in the catchment is measured by eight station rain gauges and two ombrographs connected with the NOEL automatic meteorological station. Other characteristics of the soil and air sphere are also determined as well as the dynamics of air pollution flow by a summation method. Vertical seepage onto the bedrock using ten lysimeters placed at a depth of 0.75 m with a total area of 1 m^2 and lateral subsurface flow from the boundary line of organic and mineral horizons and from the boundary line of more loose and more compacted mineral layers were also measured. Groundwater table is monitored by 52 water table measuring pipes placed in two transects (perpendicularly to the contour and across ditches) and on four microplots differing in vegetation cover (peat moss, reed, hair-grass and mixed growth). Suction pressure of soil is measured by 168 tensiometers at a depth of 0.30, 0.45, 0.60 m in two microplots (10x10 m) differing in moisture. The outflow (discharge) in the watercourse was monitored by a METRA float recording gage. Since 1996, the outflow is recorded by a NOEL combined float and manometer recording gage with automatic data collection.

Procedure of evapotranspiration assessment

The new method of calculating evapotranspiration from decrease of day discharge in comparison with night one was developed. The procedure was demonstrated on computed example by Fig. 1 and 2 and it is a part of the next passage. Theoretically and methodically the procedure was supported also by Lee's contemplation (1980) presented in his book Forest hydrology. He stated that areas where groundwater is near the surface, trees draw water from the capillary fringe causing fluctuations in the level of the groundwater table; near small headwater streams, diurnal cycles of water level and stream discharge are distinct. The pattern of fluctuation can be used to estimate the total pumping effect (water use) of the forest. Assuming that evapotranspiration is negligible during the first few hours after midnight,

$$E\ (\text{mm/day}) = 24\ S_y\ (s_r - s_d),$$

where S_y is the specific yield of the underlying aquifer, s_r (in mm/hour) is the slope of the recharge segment (early morning), and s_d the corresponding slope of interdiurnal groundwater depletion. Lee (1980) also attached a figure where diurnal cycle of shallow groundwater level caused by evapotranspiration is pictured (a copy of the picture is possible to obtain from the authors).

Results and discussion

The procedure of calculating evapotranspiration from decrease of day discharge in comparison with night one is presented on example of a long time draught period in August 1997 (Figs 1 and 2). We examined the decrease of day discharge against night one from streamflows received by a manometric water-level recorder in the closing profile of the catchment. We analysed drought periods in May, June, August, and September 1997 and in May, June, July, August, and September in 1998 and used them for computing of water loss in discharge. In our special conditions the water loss per daytime ranged from 22 000 to 87 000 litres. We estimated possible lateral drainage reach of open ditches and natural streams (forming drainage network) on base of average particle-size distribution of the soils in our catchment using the Czech Government Standard No. ČSN 75 4200: Treatment of water regime of agriculture soils by drainage. The use of agricultural procedures was not fully precise on computing values for non-homogeneous forest soils; nevertheless, its precision was sufficient for given purpose. Total length of drainage ditches and natural streams 1 180 m and their assumable bilateral hydraulic reach 9 m resulted in computed probable evapotranspiration area, influencing directly discharge, equalled to 2.12 ha.

If we recalculated the mean daytime loss of discharge equalled to 45 000 l on the probable area influenced by drainage network, we obtained expression of runoff-depth loss in millimetres, i.e. 2.1 mm per day. The daily values of runoff-depth loss, computed for discharge loss interval 22 000 to 87 000 l, ranged from 1.1 to 4.1 mm per day. The range of values corresponded with transpiration and evapotranspiration data reported by Ladefoged (1963), Střelcová et al. (2004), Kantor (in Krečmer et al., 2003), and most recently Šach et al. (2006).

Ladefoged (1963) stated maximum daily transpiration 1.9–4.9 mm per day for a mature Norway spruce stand and 2.2–4.8 mm per day for a mature European beech one under optimal climatic conditions. On the basis of his experiments in spruce stands he further specified

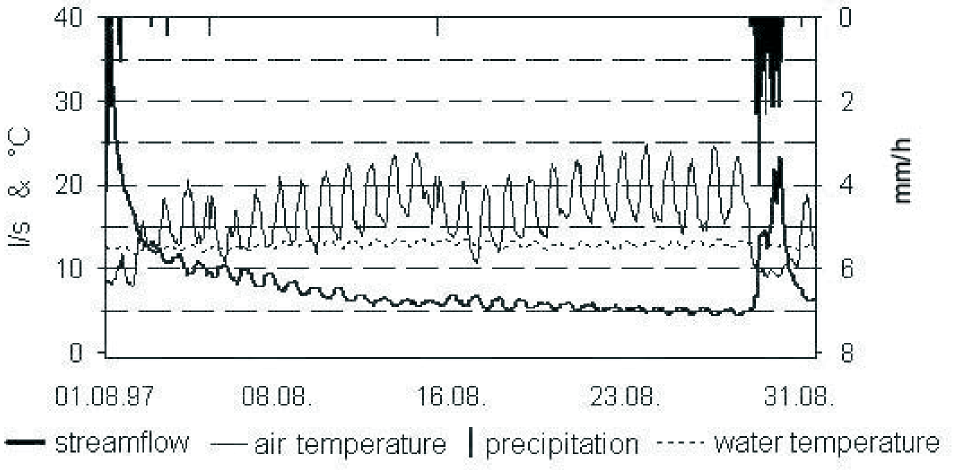

Fig. 1. The run of streamflow, water and air temperatures and precipitation in August 1997.

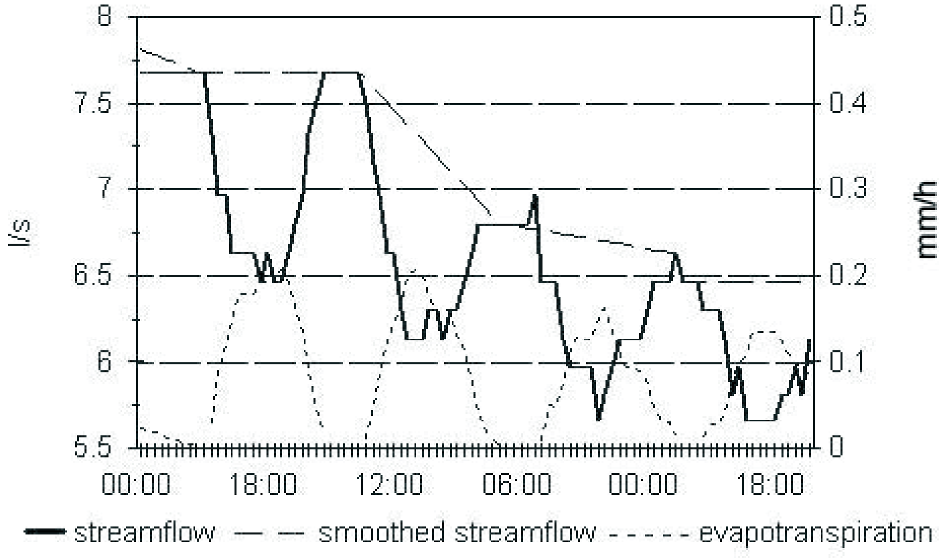

Fig. 2. Streamflow, smoothed streamflow and calculated evapotranspiration from 10. 8. to 13. 8. 1997.

interval of transpiration: 1.3–3.2 mm per day for the period of May to August (September). Střelcová et al. (2004) stated daily smoothed values of transpiration for a mature beech group in the Polana Mt. (the Slovak Republic) at an elevation of 850 m, calculated on the one hand from the measured sap flow and on the other hand using the SVAT model, for the period June–July 1996 in the range from 1.1 to 6.0 mm with mean value 1.6 mm per day.

Kantor (in Krečmer et al., 2003) used his many years' investigation of water balance in Norway spruce stand and European beech one in the Orlické hory Mts for estimation of daily value of evapotranspiration. Young spruce or beech stand (from thicket to pole stand) gives daily evapotraspiration for cloudy spring, summer, and autumn day 1.1, 2.0, 1.0 mm respectively, for sunny spring, summer, and autumn day 2.6, 4.4, 2.5 mm respectively. Clear-cut with heavy weed infestation shows practically the same data: 1.1, 2.2, 1.0 mm respectively 2.6, 3.7, 2.4 mm. The interval of evapotraspiration 1.0–4.4 mm per day by Kantor is very close to interval 1.1–4.1 that we established for similar natural conditions on our experimental catchment U Dvou louček.

Šach et al. (2006) derived daily evapotranspiration from decrements continuously recorded volume soil moisture in young closed stands in the Orlické hory Mts. Daily evapotranspiration of spruce pole-stage stand and beech pole-stage one ranged in rainless days of June 2005 from 1.3 to 3.3 mm respectively from 1.2 to 4.5 mm. The evapotranspiration range from 1.2 to 4.5 mm again supported the range 1.1–4.1 mm from the examined catchment.

On the basis of above mentioned comparisons we suppose that in cold and humid conditions of mountain areas, where evapotranspiration is restricted more by heat balance than water supply (Krečmer et al., 2003), we can consider the evapotranspiration, assessed by the described procedure, to be representative for the whole catchment area in rainless period. We further prepare refinement of evapotranspiration values in dependence on air temperature, humidity and flow and on energy of solar radiation.

Conclusion

Existing and our new knowledge about influence of evapotranspiration on discharge variations in conditions of the partially waterlogged catchment are summarized. During summer rainless periods the daily discharge fluctuations of streamflow, which drained waterlogged pedon, were in accordance with the theory of authors doing research in similar natural conditions; they also consider the evapotranspiration in riparian vegetation to be the main cause of diurnal variation of streamflow. On the basis of examined streamflow fluctuation and numerically estimated partially area of the catchment directly hydraulically connected with drainage network, we computed values of evapotranspiration equal ranging from 1.1 to 4.1 mm per day with mean value 2.1 mm/day. The values agree with other author data assessed by different methods in similar humid mountain conditions. Therefore we suppose the method could be generalized for rainless periods of mountain humid regions of the Czech Republic.

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References

Bren, L.J., 1997: Effects of slope vegetation removal on the diurnal variations of a small mountain stream. Water Resources Research, *33*, 2: 321–331.

Constantz, J., Thomas, C.L., Zellweger, G., 1994: Influence of diurnal variations in stream temperature on streamflow loss and groundwater recharge. Water Resources Research, *30*, 12: 3253–3264.

Constantz, J., 1998: Interaction between stream temperature, streamflow, and groundwater exchanges in alpine streams. Water Resources Research, *34*, 7: 1609–1615.

ČSN 75 4200, 1994: Treatment of water regime of agriculture soils by drainage (in Czech). Praha.

Kobayashi, D., Suzuki, K., Nomura, M., 1990: Diurnal fluctuation in stream flow and in specific electric conductance during drought periods. Journal of Hydrology, *115*: 105–114.

Kobayashi, D., Kodama, Y., Ishii, Y., Tanaka, Y., Suzuki, K., 1995: Diurnal variations in streamflow and water quality during the summer dry season. Hydrological Processes, *9*, 7: 833–841.

Krečmer, V., Kantor, P., Šach, F., Švihla, V., Černohous, V., 2003: Forests and floods (in Czech). Ministerstvo životního prostředí, Praha, 48 pp.

Ladefoged, K., 1963: Transpiration of forest trees in closed stands. Physiol. Plant., *16*, 2: 378–414.

Lee, R., 1980: Forest hydrology. Columbia University Press, New York, 349 pp.

Ronan, A.D., Prudic, D.E., Thodal, C.E., Constanz, J., 1998: Field study and simulation of diurnal temperature effects on infiltration and variably saturated flow beneath an ephemeral stream. Water Resources Research, *34*, 9: 2137–2153.

Střelcová, K., Matejka, F., Kučera, J., 2004: Beech stand transpiration assessment – two methodical approaches. Ekológia (Bratislava), *23*, Suppl. 2: 147–162.

Šach, F., Kantor, P., Černohous, V., 2000: Forest ecosystems, their management by man and floods in the Orlické hory Mts in summer 1997. Ekológia (Bratislava), *19*, 1: 72–91.

Šach, F., Kantor, P., Černohous, V., 2006: Determination of evapotranspiration of young Norway spruce stand and European beech one by method of continual measurement of volumetric moisture in soil profile (in Czech with English summary and caption). In Jurásek, A., Novák, J., Slodičák, M. (eds), Stabilization of forest functions in biotopes disturbed by anthropogenic activity. Výzkumný ústav lesního hospodářství a myslivosti – Výzkumná stanice, Opočno, p. 525–536.