The Comparison of Water and Matter Flows in Three Small Catchments in the Šumava Mountains

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Abstract: The comparisons of water and matter flows have been evaluated in three small catchments with different land uses in the Šumava Mountains in the south-west of the Czech Republic since 1999. The catchment of the Mlýnský stream was artificially drained, the areas of the catchment retaining the character of drained, semi-intensive pasture. The catchment of the Horský stream is covered with forest, mowed meadows, and locations with natural succession (wetlands). The catchment of the Bukový stream is covered with forest, mostly with spruce monoculture. The highest amount of water was discharged from the drained Mlýnský catchment whereas the amounts of water discharged from the Horský and Bukový catchments were lower. The runoff maxima in the hydrologic year of 2002 were recorded in the Mlýnský stream catchment in August – at the time of the catastrophic floods. On the other hand, the maximum discharges in the Horský and Bukový stream catchments in August 2002 were comparable with those that occurred in the spring during the snow melt. In comparison, the water chemistry showed relationships between trends and features and the results of water runoff. The comparison of the runoff and matter flows in the catchments studied confirmed the influence of the land cover and management in both normal and extreme rainfall-runoff conditions.

Keywords: water cycle; runoff; water chemistry; matter discharge; vegetation

The aspects of the matter losses and fluctuations of the runoff from a catchment are very important. In these processes, the vegetation has a notable role. The natural vegetation cover retains moisture and provides optimised temperature damping through evapotranspiration and condensation processes and in such a way maintains optimal conditions for ecosystem functioning (Ripl 2003). Minimal matter losses through the water discharged from a given catchment are of both ecological and economic interests. Mineralisation and fast matter outflow, namely the losses of base cations (calcium, magnesium, potassium), are associated with soil acidification on one hand and water eutrophication on the other hand. The impaired vegetation cover cannot retain water. Therefore, evapotranspiration decreases and water outflow becomes faster and irregular. Both the matter losses from the landscape and the sedimentation rate increase.

The concept of the landscape efficiency based on the matter losses and solar-energy dissipation defined by Ripl (1995) was tested in three small catchments in the Šumava Mountains (the Bohe-

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mian Forest, Czech Republic). Previous studies had shown that different land uses in small catchments resulted in different land covers, long term changes of water chemistry, different matter losses, and different temperature distributions (Procházka *et al.* 2001, 2006, 2008). The aim of this study is the comparison of the runoff fluctuations, water budget, water chemistry, and matter losses in the catchments differing in the character of the land cover and management practices.

MATERIAL AND METHODS

The small catchments studied are located in the Šumava Mountains in the border region between Austria and the Czech Republic (Figure 1). The catchments of the Mlýnský, Horský, and Bukový streams represent three different types of land cover. They had been managed similarly till the 1950s, afterwards the Mlýnský catchment (212.8 ha) was drained and used mostly for grazing, the rate of forested/deforested area being kept at 1:10. In the Horský catchment (206.3 ha), the forest and wetlands areas increased from 24% in 1950s to 71% in 1999, and in the Bukový catchment (221 ha) the proportion of the deforested area decreased from 55% in 1950s to 5% in 1999 (Procházka *et al.* 2001).

The current vegetation cover in the stream catchments had been recorded from 1998 to 2000, following the modified methodology created by the management of the Šumava National Park and GEF project – Biodiversity (Hakrová 2003).

The geology of all the catchments is primarily represented by granite. Soils are mostly acidic brown soils (cambisol) (Procházka *et al.* 2008).

The precipitations were measured at two stations: Svatý Tomáš (Czech Hydrometeorological Institute), and Pasečná (Applied Ecology Laboratory) (Figure 1). Since 1999, the daily precipitation measurements and weekly integrated samples for chemical analysis of atmospheric deposition have been collected and automatic stations monitoring the water levels have been operating at the outlets of each of the catchments. The water level (by pressure and ultrasonic sensors), conductivity, and temperature of the discharged water have been continuously recorded. The flow rating curves were determined using the measurements made by the current meter OTT C2 (Ott Messtechnik, Kempten, DE) and derived discharge rating curves.

Two following intervals were chosen for the comparison of the runoffs in the monitored catchments:

(1) The hydrologic year 2002 (November 1, 2001–October 31, 2002) with the period of spring snow melt and that of catastrophic floods in August 2002 (catastrophic floods in the Czech Republic in 2002 (August 6–22)) in the basins of the Vltava, Labe, and Dyje rivers (Šálek *et al.* 2002; Řezáčová *et al.* 2005);

(2) The summer period of 2008 (July 28–August 25, 2008) with two majors rainfall events.

Water budgets for the hydrological years 1999–2007 were calculated from the data of total precipitation and total runoff at the outlets of the catchments. Matter budgets of the selected ions were calculated from the results of chemical analyses and the amounts of precipitated and discharged water.

In the collected water samples, the values of pH and alkalinity (by potentiometric titration with 0.1M HCl) were measured. Cations Ca^{2+}, Mg^{2+}, K^{+}, Na^{+} were determined by AAS method with Varian SpectrAA-640 instrument. Other major ions, Cl^{-} and SO_4^{2-}, and the forms of N and P were determined by flow injection analysis on Tecator FIA-Star instrument (Procházka *et al.* 2001).

For comparable testing of the differences between the catchments, we used the following statistical approaches. The differences between the chemistry of

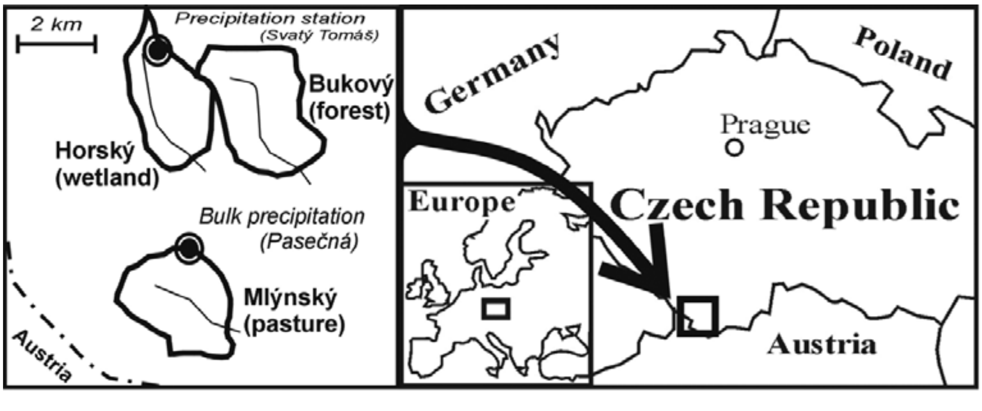

Figure 1. Location of the study area

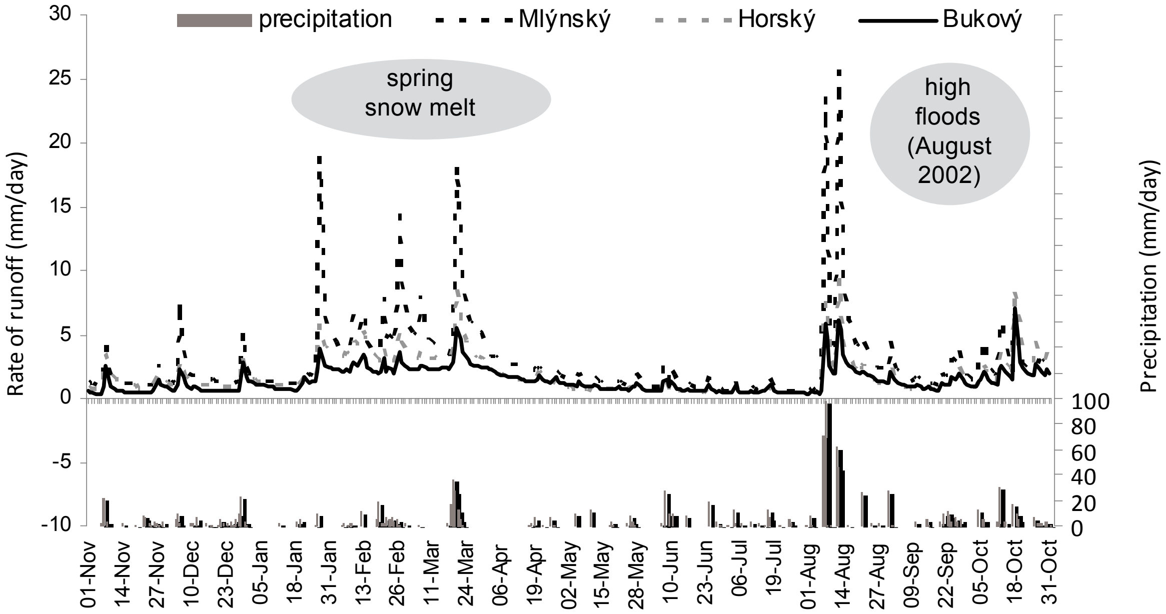

Figure 2. Daily precipitation and runoff in hydrologic year 2002

the water discharged from the streams were tested using one-way ANOVA. The runoff rates from the catchments were compared using Friedman test. This test was used because the data did not prove the normal distribution. Because Friedman test is not able to show the differences between pairs of the characteristics tested, we used the combination of *t*-tests for dependent samples. We believe the *t*-test is applicable to our data because they are correlated. In order to keep the probability of Type I error on the nominal significance level, a Bonferroni correction was applied (Salkind 2007). The 5% probability level was used for statistical analyses. We used Statistica 7.1 software (StatSoft Inc. 2005) for all tests.

RESULTS

The mean discharges of the monitored catchments as calculated for the daily data from period 1999–2007 are relatively comparable. The Mlýnský catchment had the highest average discharge (55 l/s). The Horský catchment had the lowest mean discharge (43 l/s), the mean discharge from the Bukový catchment was 46 l/s.

The courses of the runoffs in hydrologic year 2002 are demonstrated in Figure 2. This series of the runoffs includes the periods of the spring snow melt as well as the catastrophic flood in August 2002. The August flood had two peaks. The first one occurred on August 6th–7th (total precipitation at the Pasečná station during the two days was 170 mm), and the second one occurred on August 11th–12th (total precipitation 110 mm). The corresponding daily runoffs were: in the Mlýnský stream 23.5 mm and 25.6 mm in the Horský stream 7.6 mm and 9.4 mm, and in the Bukový stream 5.9 mm and 6.2 mm, respectively. For comparison, maximum daily runoff during the spring period of 2002 was 18.9 mm in the Mlýnský stream catchment, 8.6 mm in the Horský stream catchment, and 5.6 mm in the Bukový stream catchment, respectively.

The courses of the mean daily runoffs in the summer of 2008 (Figure 3) represent a standard summer period with two majors rain occurrences, the first one having been short and intensive (July 31th = 46 mm), and the second one lasting two days (August 15th and16th = 49 mm). In both cases, the highest runoff was recorded in the Mlýnský stream catchment. This catchment had also the highest runoff variability expressed as the standard deviation of daily values (Figure 4).

The statistical comparison of the runoffs in the two periods presented shows that the runoff rates of the individual catchments were significantly different, both in the summer 2008 ($\chi^2 = 52.62$, $N = 29$, df = 2, $P < 0.001$) and in the hydrologic year 2002 ($\chi^2 = 508.28$, $N = 365$, df = 2, $P < 0.001$). The runoffs of the Mlýnský catchment were significantly different in comparison to the Horský and Bukový streams (*t*-test's combination with

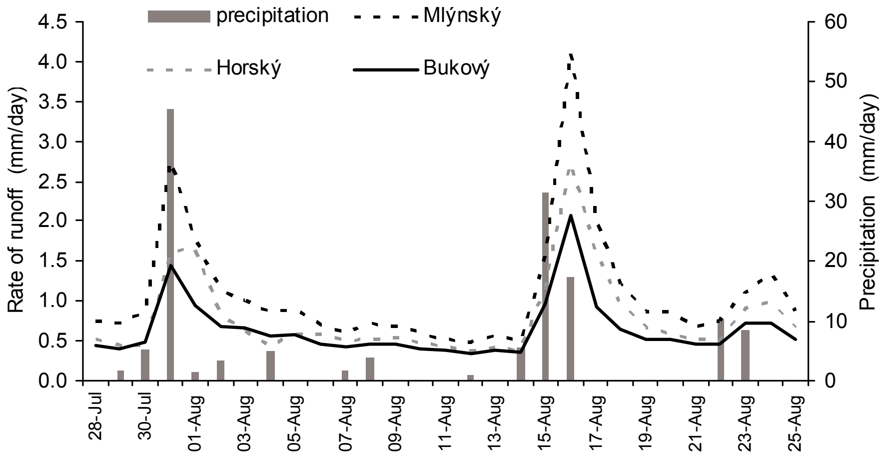

Figure 3. Daily precipitation and runoff in summer 2008 (July 28–August 25)

Bonferroni correction of P-level; $P < 0.001$). The runoff fluctuations characterised by standard deviations were evidently higher in the Mlýnský stream catchment than in the Horský stream and Bukový stream catchments. The standard deviations for the studied periods were: 0.77 (in the summer of 2008) and 3.12 (in hydrologic year 2002) for the Mlýnský, 0.53 and 1.54 for the Horský stream, and 0.36 and 0.10 for the Bukový stream catchments, respectively (Figure 4).

The total precipitation and the total catchment runoff were used for the precipitation-discharge budget calculations. The proportions of the sums of precipitation and runoff in particular catchments varied considerably during the period of 1999–2007 (Table 1). While the ratio of the not-discharged water from the catchment to precipitation was approximately 10% in the Mlýnský stream catchment, it was noticeably larger both in the Horský (41%) and Bukový (54%) streams catchments.

The comparison of the catchments based on the water chemistry and discharged amounts of dissolved solids showed analogical results. The total content of dissolved matter, expressed as conductivity, as well as average concentrations of hydrocarbonates, nitrates, calcium, magnesium, sodium, potassium, and chlorides, were significantly higher in the Mlýnský stream than in the Horský and Bukový streams. The results of the 'one-way ANOVA' proved differences between the catchments on 1% significance levels, except for sulphate (5%) and ammonium (non-significant) contents (Table 2).

The matter losses from the individual catchments calculated from the concentrations of the matter in water and the amount of water discharged and expressed in kilograms per hectare and per year are given in Figure 5. In comparison with the total deposition, the highest losses for all ions were found in the water from the Mlýnský catchment. The total amount of annual losses of Ca^{2+}, NO_3^-, and Mg^{2+} from the Mlýnský catchment was 3 to 5 times higher than those from the other two catchments. About 60 kg/ha of Ca^{2+} and approximately the same amount of NO_3^- together are transported annually from the Mlýnský catchment.

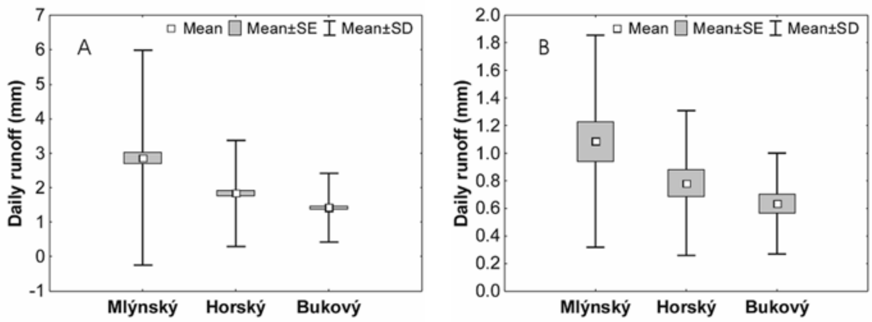

Figure 4. Mean values, standard error of the mean (SE) and standard deviation (SD) of the runoffs data for the hydrologic year 2002 (A) and for August of 2008 (B)

Table 1. Water budgets in the catchments during the period of 1999–2007 (m^3/ha/year and % of balance of the not-discharged water from the catchments)

Catchment		1999*	2000	2001	2002	2003	2004	2005	2006	2007	Average	%
Mlýnský	precipitation	900	1102	934	1285	897	935	839	857	970	969	
	runoff	810	1093	734	1244	775	811	755	771	873	874	10
Horský	precipitation	937	1194	1007	1511	949	993	910	950	1150	1067	
	runoff	553	656	538	839	645	675	537	561	679	631	41
Bukový	precipitation	937	1194	1007	1511	949	993	910	950	1150	1067	
	runoff	431	462	478	645	486	550	419	437	529	493	54

*Annual outflow from 1999 was estimated by regular measurements and total precipitation

DISCUSSION

The comparison of the water and matter flows in dependence on the management practices were examined in three small catchments. The long-term landscape management (after World War II) decided on different vegetation covers on the catchments studied. The areas of the Bukový stream catchment were forested by the spruce, thereby are mismatched with the potential natural vegetation cover (Neuhäslová 2001). Nevertheless, from the point of view of the runoff variability, it may be expected that they perform similarly like a natural forest. In the Horský stream catchment, 30% of the deforested area is covered by secondary grasslands, typical of the traditional farming land in the Šumava Mountains (Prach *et al.* 1996), and wetlands including waterlogged forests, peat meadows, and peat-bog (Dohnal *et al.* 1965; Chytil *et al.* 1999; Spitzer & Buffková 2008). The vegetation cover of the Mlýnský stream catchment is the result of the most intensive farming practices – including large-scale drainage – thus being far from both the potential natural vegetation and the valuable secondary grassland communities (Hakrová 2003). It is known that the vegetation conditions influence the hydrologic cycle in the landscape (Gordon *et al.* 2005; Piao *et al.* 2007; Wattenbach *et al.* 2007). Šír *et al.* (2008) studied the synergy between the hydrologic extremes, plant

Table 2. Mean bulk precipitation chemistry and stream water chemistry during the period of 1999–2007 (conductivity in μS/cm, alkalinity in mEq/l, the others in mg/l)

Parameter	Precipitation			Mlýnský			Horský			Bukový			ANOVA
	N	$\bar{x}$	SD	*N*	$\bar{x}$	SD	*N*	$\bar{x}$	SD	*N*	$\bar{x}$	SD	*F; P*
Conductivity	327	32.4	21.0	128	90.9	16.8	130	42.7	7.5	128	36.0	4.2	978.52***
pH	337	5.31	0.6	135	6.38	0.3	135	6.09	0.4	134	6.06	0.6	20.65***
Alkalinity	303	0.18	0.1	134	0.46	0.1	133	0.20	0.1	130	0.15	0.1	282.72***
NO_3^-	331	2.03	1.6	135	7.39	2.7	133	2.01	1.1	133	1.40	0.5	374.13***
Ca^{2+}	336	0.98	1.2	125	7.75	2.4	126	3.20	1.4	125	2.36	0.7	379.46***
Mg^{2+}	335	0.22	0.4	126	1.62	0.5	126	0.88	0.5	126	0.67	0.3	152.53***
Na^+	336	0.43	0.4	125	3.76	1.1	126	2.71	0.9	126	2.78	0.9	45.47***
K^+	335	0.63	0.6	125	1.61	0.3	126	1.07	0.3	126	0.58	0.4	233.23***
NH_4^+	331	0.87	1.4	125	0.04	0.1	136	0.03	0.1	136	0.03	0.1	1.62 n.s.
Cl^-	332	1.11	2.1	135	1.66	1.1	136	1.01	0.6	134	0.86	0.5	38.60***
SO_4^{2-}	310	6.10	6.0	134	13.6	6.7	134	11.2	6.4	132	11.3	7.5	5.38**

N – Number of cases; $\bar{x}$ – mean; SD – standard deviation; *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$; n.s. – not significant; degrees of freedom = 2 in each cases; one-way ANOVA was computed for streams only

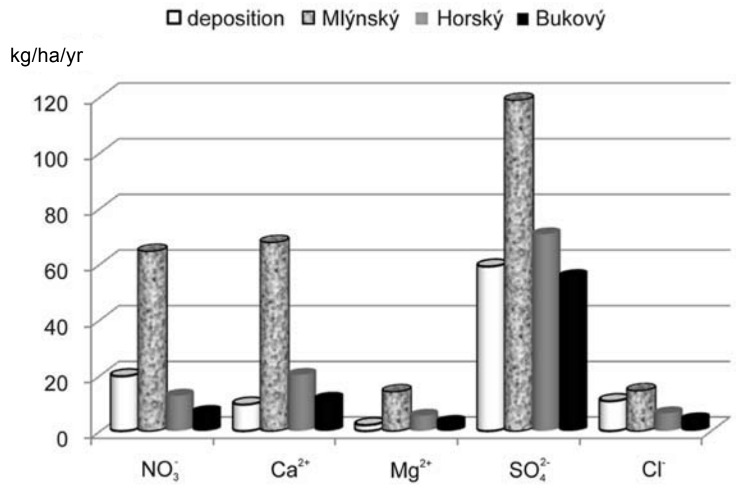

Figure 5. Comparison between the average matter budgets in the catchments during the period of 1999–2007 (kg/ha/year)

transpiration, gross primary productivity, and soil water retention in the experimental catchment Zábrod-Meadow in the Šumava Mountains. Their results also show that, in the case of sufficient soil water retention, high entropy production by transpiration and high gross primary productivity lead to the stability of the hydrologic cycle. This certainly presumes sensible management with the soil and vegetation cover.

Tesař *et al.* (2008) pointed out that neither the soil cover in the catchment nor the fluvial deposits along the Modrý potok stream (the Krkonoše Mountains, Czech Republic) were able to retain extreme rains and inhibit catastrophic floods. The floods in August 2002 (in the Czech Republic) were extreme, but the results obtained with the three catchments presented in this study proved noticeable differences between the runoff rates. Runoff maxima in the hydrologic year of 2002 were recorded in the Mlýnský stream catchment in August – at the time of the catastrophic floods. On the other hand, the runoff maxima in the Horský and Bukový stream catchments in August 2002 were comparable with the spring maxima connected with the snowmelt. The runoff measurements in the summer of 2008 confirmed the occurrence of the highest values in the Mlýnský stream catchment. This contributes to our assertion that the land cover and management practices in the landscape influence markedly the water and matter flows and energy fluxes. Not only through common conditions, but also during extreme occurrences.

In comparison, the respective chemistry showed similarity in trends and features with the results of water runoff described above. The chemical composition of the waters discharged from the three studied catchments of the Šumava Mountains is controlled by the processes in soil. Considering granite as the main geological substrate in the catchments studied, no accumulation of Ca^{2+} in groundwater and therefore no subsequent effect of groundwater on Ca^{2+} content in the discharged water is expected (Stevens *et al.* 1989). The annual mean concentrations of base cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) in bulk precipitation were relatively low and constant over the period monitored (Procházka *et al.* 2008). Substantially higher concentrations of all base cations were found in the runoff from the Mlýnský catchment in comparison with the Horský and Bukový catchments, although the storage (pool) of these ions in the soil of the Mlýnský catchment is the lowest (Procházka *et al.* 2001).

Nitrate concentration in bulk precipitation in the study area moderately increased, even though NO_3^- concentration in the stream water markedly decreased by the effect of non-fertilising after the change of the political situation in 1989 (Procházka *et al.* 2008). Our findings of the annual deposition of 18 kg NO_3^- per hectare (Procházka *et al.* 2006) agree well with the annual matter depositions in the areas of GEOMON catchments monitoring network described by Fottová (2003). However, the Mlýnský stream catchment discharged four times more NO_3^- in comparison with its atmospheric deposition and six times more than was its discharge from the Horský and Bukový catchments. We suppose that the considerably higher losses of ions from the Mlýnský catchment resulted from the drainage and subsequent mineralisation and acidification of soil (Procházka *et al.* 2006). This process of 'soil acidification', i.e. removing base cations that can neutralise the acid rain, might be more important than the impact of the acid rain itself (Thimonier *et al.* 2000). Ress and Ribbens (1995) showed the exacerbated problem of a long-term acid deposition and, more recently, large-scale aforestation in the region of Galloway (Scotland, UK) in relation to the soil and water acidification. Majer and Veselý (2005) also described the changes of the freshwater composition in the National park Šumava Mountains under the changes of natural conditions and forest management.

The Mlýnský stream catchment also shows a lower performance of the landscape functions in terms of other parameters, such as the lowered water-retention capacity and the lowered quality of the surface water leaving the catchment. In contrast to the Mlýnský catchment, the natural vegetation cover of the Horský and Bukový catchments retains moisture and provides optimal temperature dampening through evapotranspiration and condensation processes (Brom & Pokorný 2009). In accorddance with Ripl (2003), our results showed a decrease of the matter losses and a moderation of the runoff fluctuation from the areas with natural vegetation. We suppose that the management may have a crucial impact on the hydrological regime of the landscape through the changes of the vegetation cover.

CONCLUSION

The comparison of the water and matter flows have been evaluated since 1999 in three small catchments with different land uses in the Šumava Mountains in south-west of the Czech Republic. The catchment of the Mlýnský stream was drained and the areas of the catchment retained the character of drained, semi-intensive pasture. The catchment of the Horský stream is covered with forest, mowed meadows, and locations with natural succession (wetlands). The catchment of the Bukový stream is covered with forest, mostly with the spruce monoculture. On the basis of the water budget, we found out that the highest ratio between the not-discharged water and precipitation occurred in the catchments of the Bukový and Horský streams, while the catchment of the Mlýnský stream loses the highest amount of water and shows the highest fluctuations of the outflow. This indicates that the land use markedly affects the water, matter, and energy flows, not only through common conditions, but also during extreme occurrences. Similar results were found by comparison of the respective water chemistry and matter discharge. The highest conductivity (amount of dissolved matter) and ions concentrations in the outflow water was repeatedly recorded at the closing profile in the catchment of the Mlýnský stream; the lowest at the closing profile of the Bukový stream. Out of all ions, the highest losses were found with the Mlýnský catchment despite the storage of matter being relatively low. The transports of nitrate, sulphate, and calcium are several times higher from the Mlýnský catchment than from the others. The high water outflow, runoff fluctuations, and high concentrations of matter in water synergistically increased the matter transport from the Mlýnský catchment.

The high level of results similarity between the water budget, runoff fluctuation, and leaching of dissolved substances is documented by before now presented data about the vegetation, biomass, land cover temperature, and wetness coming from the three small study catchments. This implies that human activities influence significantly the changes of water and in biogeochemical cycles.

References

Brom J., Pokorný J. (2009): Temperature and humidity characteristics of two willow stands, a peaty meadow and a drained pasture and their impact on landscape functioning. Boreal Environment Research, **14**: 389–403.

Chytil J., Hakrová P., Hudec K., Husák Š., Jandová J., Pellantová J. (eds) (1999): Wetlands of the Czech Republic – The List of the Water and Wetland Localities. Czech Ramsar Committee, Mikulov. (in Czech)

Dohnal Z., Kunst M., Mejstřík V., Raučina Š., Vydra V. (1965): Peatlands and Moorlands of the Czechoslovakia. Academia, Praha. (in Czech)

Fottová D. (2003): Trends in sulphur and nitrogen deposition fluxes in the GEOMON network, Czech Republic, between 1994 and 2000. Water, Air, & Soil Pollution, **150**: 73–89.

Gordon L.J., Steffen W., Jönsson B.F., Folke C., Falkenmark M., Johannessen Å. (2005): Human modification of global water vapour flows from the land surface. Proceedings of the National Academy of Sciences of the United States of America, **102**: 7612–7617.

Hakrová P. (2003): The research of conditions of the support of the specific diversity grasslands. [Ph.D. Thesis.] University of South Bohemia in České Budějovice, Faculty of Agriculture, České Budějovice. (in Czech)

Majer V., Veselý J. (2005): Freshwater composition in the Šumava National Park. Silva Gabreta, **11**: 69–81. (in Czech)

Neuhäuslová Z. (ed.) (2001): Map of Potential Natural Vegetation of the Czech Republic. Academia, Praha. (in Czech)

Piao S., Friedlingstein P., Ciais P., de Noblet-Ducoudré N., Labat D., Zaehle S. (2007): Changes in climate and land use have a larger direct impact than rising CO_2 on global river runoff trends. Proceedings of the National Academy of Sciences of the United States of America, **104**: 15242–15247.

Prach K., Štech M., Beneš J. (1996): Secondary grasslands – a neglected component of biodiversity in the Šumava Mts. Silva Gabreta, **1**: 243–247. (in Czech)

Procházka J., Hakrová P., Pokorný J., Pecharová E., Hezina T., Wotavová K., Šíma M., Pechar L. (2001): Effect of different management practices on vegetation development, losses of soluble matter and solar energy dissipation in three small sub-mountain catchments. In: Vymazal J. (ed.): Transformations of Nutrients in Natural and Constructed Wetlands. Backhuys Publishers, Leiden, 143–175.

Procházka J., Včelák V. Wotavová K., Štíchová J., Pechar L. (2006): Holistic concept of landscape assessment: case study of three small catchments in the Šumava Mountains. Ekológia (Bratislava), **25** (Suppl. 3): 5–17.

Procházka J., Brom J., Pechar L., Štíchová J., Pokorný J. (2008): Changes in concentrations of dissolved solids in precipitation and discharge water from drained pasture, natural wetland and spruce forest during the years of 1999–2006 in Šumava Mountains, Czech Republic. In: Vymazal J. (ed.): Wastewater Treatment, Plant Dynamics and Management. Springer Science + Bussines Media B.V., Heidelberg, 39–51.

Rees R.M., Ribens J.C.H. (1995): Relationships between afforestation, water chemistry and fish stock in an upland catchment in south-west Scotland. Water, Air & Soil Pollution, **85**: 303–330.

Ripl W. (1995): Management of water cycle and energy flow for ecosystem control – the Energy-Transport-Reaction (ETR) model. Ecological Modelling, **78**: 61–76.

Ripl W. (2003): Water: the bloodstream of the biosphere. Philosophical Transaction, the Royal Society of London B, **358**: 1921–1934.

Řezáčová D., Kakos V., Kašpar M., Müller M., Pešice P., Sokol Z. (2005): A comparison of flood precipitation in August 2002 with historical extreme precipitation events from the Czech territory. Atmospheric Research, **77**: 354–366.

Salkind N.J. (ed.) (2007): Encyclopedia of Measurement and Statistics. Sage Publications, Inc., Thousand Oaks.

Spitzer K., Bufková I. (2008): Peat Bogs of the Šumava Mountains. Šumava National Park and Protected Landscape Area, Vimperk. (in Czech)

StatSoft, Inc. (2005): STATISTICA (Data Analysis Software System), Version 7.1. www.statsoft.com.

Stevens P.A., Hornung M., Hughes S. (1989): Solute concentration, fluxes and major nutriet cycles in mature Sitka spruce plantation in Beddgelert Forest, North Wales. Forest Ecological Management, **27**: 1–20.

Šálek M., Novák P., Kráčmar J. (2002): The utilization of the remote sensing methods during the flood in the Czech Republic in August 2002. Meteorological Bulletin, **55**: 177–179. (in Czech)

Šír M., Lichner Ľ., Tesař M., Krejča M., Váchal J. (2008): Soil water retention and gross primary productivity in the Zábrod area in the Šumava Mts. Soil and Water Research, **3** (Special Issue 1): S130–S138.

Tesař M., Šír M., Lichner L., Fišák J. (2008): Extreme runoff formation in the Krkonoše Mts in August 2002. Soil and Water Research, **3**: (Special Issue 1): S147–S154.

Thimonier A., Dupouey J.L., le Tacon F. (2000): Recent losses of base cations from soil of *Fagus sylvatica* L. stands in northeastern France. Ambio, **29**: 314–321.

Wattenbach M., Zebich M., Hatterman F., Gotschalk P., Goemann H., Kreins P., Badeck F., Lasch P., Suckow F., Wechsung F. (2007): Hydrological impact assessment of afforestration and change in tree-species composition – A region case study for the Federal State of Brandenburg (Germany). Journal of Hydrology, **346**: 1–17.

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