Variability of Water Regime in the Forested Experimental Catchments

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Abstract: The water regime variability in most catchments is frequently influenced not only by the changes of the vegetation cover in the annual cycle but also by its development in the time span of decades. That means that the resulting evapotranspiration depends not only on the actual climatic situation but also on the soil moisture. The simulations of the rainfall-runoff process have been used with the intention to follow the possible role of the developing land cover. The differences between the observed and simulated flows in relatively long periods can be considered as an appropriate tool for the assessment of the water regime changes, in which the evapotranspiration demand variability is a significant phenomenon.

Keywords: vegetation change; land use; rainfall-runoff simulation; evapotranspiration demand

The water regime fluctuations and/or tendencies are induced by natural, i.e. mostly climatic oscillations, or by antropogenic activities. Climatic conditions influence the development of the vegetation cover in the annual cycle, but they also create conditions for its evolution on a scale of years. This could be also the cause of the complex variations and/or tendencies in the evapotranspiration demands and, consequently, of additional changes of the water regime. The significance of the evapotranspiration demands variability could be supported by some facts concerning the variability of solar radiation, which is in the connection with the sun spots (Beer 2005). The oscillations in the precipitations and runoffs of the Czech Labe (Elbe) River basin seem to remind of such a variability (Buchtele *et al.* 2008). The flood flow regime in south-western Germany which has been analysed by Caspary (2000) illustrates another natural change with a long term tendency.

However, the natural and stationary conditions in the basins are frequently considered as valid even in such situations when in the past some artificial changes in the water regime occurred. For example, a large system of fishponds has existed for more than four centuries and affects seriously the discharge values of the Lužnice River, which is the sub-basin of the Czech part of the Labe River basin (Figure 1). It has been estimated that during the flood in August 2002, the stored water volume in fish ponds was $W = 110–140$ mil m^3, and the retention of the largest pond Rožmberk with $W = 70$ mil m^3 was comparable with that in the Orlík Reservoir at the Vltava River, i.e. $W = 104$ mil m^3, this being significant for the protection of Prague.

Even in the recent periods, with relatively short time series and rather small basins (catchments), the situation mentioned, namely the development of evapotranspiration, creates sometimes problems

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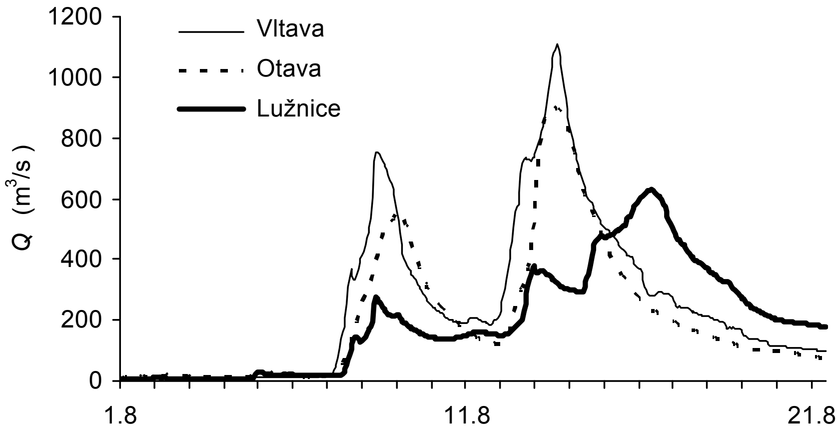

Figure 1. Surface runoff during the extraordinary flood on the Vltava River above the Orlík Reservoir in August 2002

for a reliable identification of the model parameters of the rainfall-runoff processes. Nevertheless, the rainfall-runoff models can be used as valuable tools also for ascertaining the assumed or appearing natural changes. The goal of the experiments concerning the simulations for several basins has been to gain the notion of the plausibility of historical observations, i.e. in the span of several decades.

Data and tools

The differences between the observed and simulated flows can be appropriate tools, which eventually help to re-determine the period for the proper calibration, i.e. the interval with prevailing natural and stationary conditions. In many cases the recalibration can be useful. The data from several catchments used in this presentation show that also several accidental phenomena could play a role, sometimes significant, in this context.

The models SAC-SMA (Burnash 1995) and BROOK (Federer 1995) have been calibrated for the simulation of the rainfall-runoff processes at the experimental catchments presented in Table 1. Moreover, these models have been used for the Husinec Reservoir basin, which is situated near to the Liz catchment, and for two other catchments in the vicinity, which are mostly forested.

The information on the extent and production of the vegetation cover or its yields is desirable in the simulations of many basins. Agricultural production, i.e. the yields of grain, was considered as an effective phenomenon for the water balance years ago (Keller 1970). The role of extensive deforestation in some sub-basins of the Labe River

Table 1. List of catchments and the SAC-SMA model simulation accuracy characteristics

Catchment	Time period (years)	Area (km^2)	Altitude H (m a.s.l.)		Runoff (l/s)	Precipitation (mm/year)	R (–)	Abs. dif. (%)
			H_{min}	H_{max}				
Liz Šumava Mts	30	0.989	828	1024	8.50	840	0.8192	18.1
Lysina Slavkovský les	18	0.273	829	949	2.10	896	0.8354	21.9
Pluhův Bor Slavkovský les	15	0.216	690	804	0.52	864	0.8153	27.1
Červík Beskydy Mts	50	1.850	640	960	37.90	1125	0.7452	24.8
Malá Ráztoka Beskydy Mts	53	2.080	602	1084	60.00	1243	0.8549	24.0
Husinec Šumava Mts	30	202	540	1300	420.00	860	0.8203	22.6
Lenora Šumava Mts	38	176	761	1360	556.00	1028	0.7408	23.5
Modrava Šumava Mts	38	90	973	1370	1158.00	1330	0.7631	24.2

R – coefficient of correlation between Q_{obs} and Q_{sim}; Abs. dif. – absolute standard error

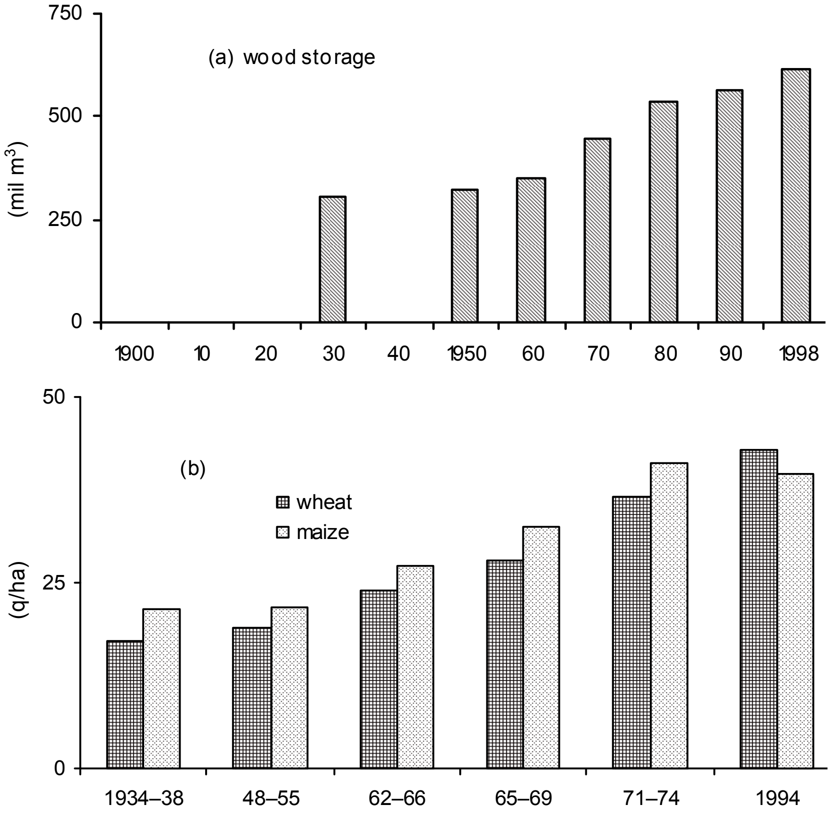

Figure 2. Variability of forest cover and grain production (in metric cents) in the Czech Republic (Anonymous 1998)

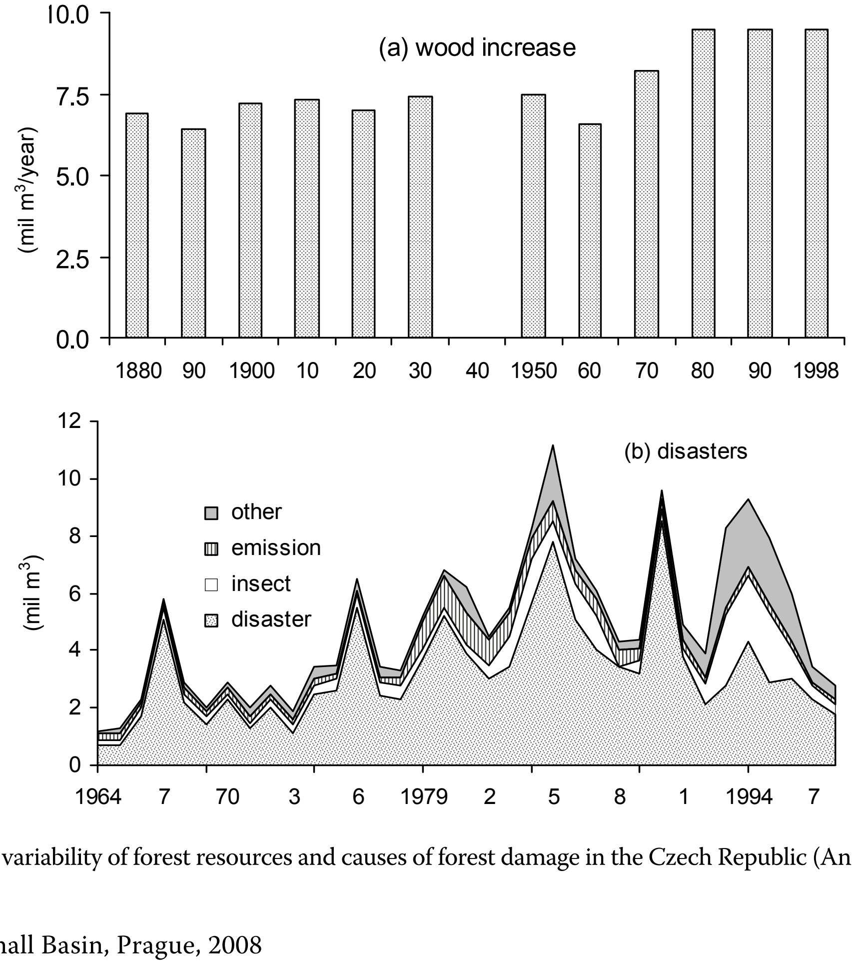

Figure 3. Long term variability of forest resources and causes of forest damage in the Czech Republic (Anonymous 1998)

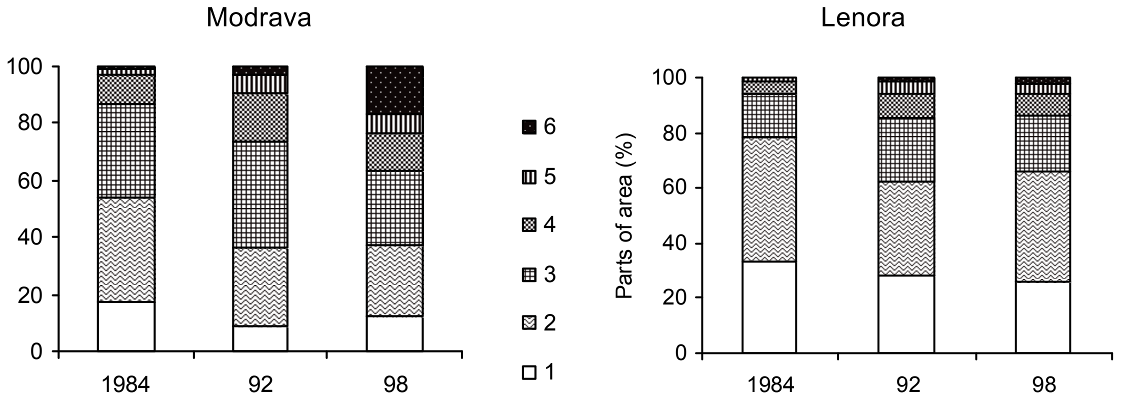

Figure 4. Forest damage in two neighbouring large catchments of the small Liz catchment – evaluated from satellite images (1 – other areas; 2 – healthy forests; 3 – slighty damaged forests; 4 – medium-damaged forests; 5 – heavily damaged forests; 6 – very heavily damaged forests)

has been an actual problem and an effort exists to simulate the runoff under these conditions (Buchtele *et al.* 2008). Figure 2 and Figure 3 illustrate the situation with the vegetation cover for the whole country during a long period of the 20th century. The forest damage in the Liz catchment and in other close catchments is presented in Figures 4 and 11.

RESULTS OF SIMULATION

Table 1 contains the main characteristics of the modelling simulation accuracy for the whole period of observation with the implementation of the model SAC-SMA.

Possible tendencies in the evapotranspiration demands have been partly mentioned in the intro-

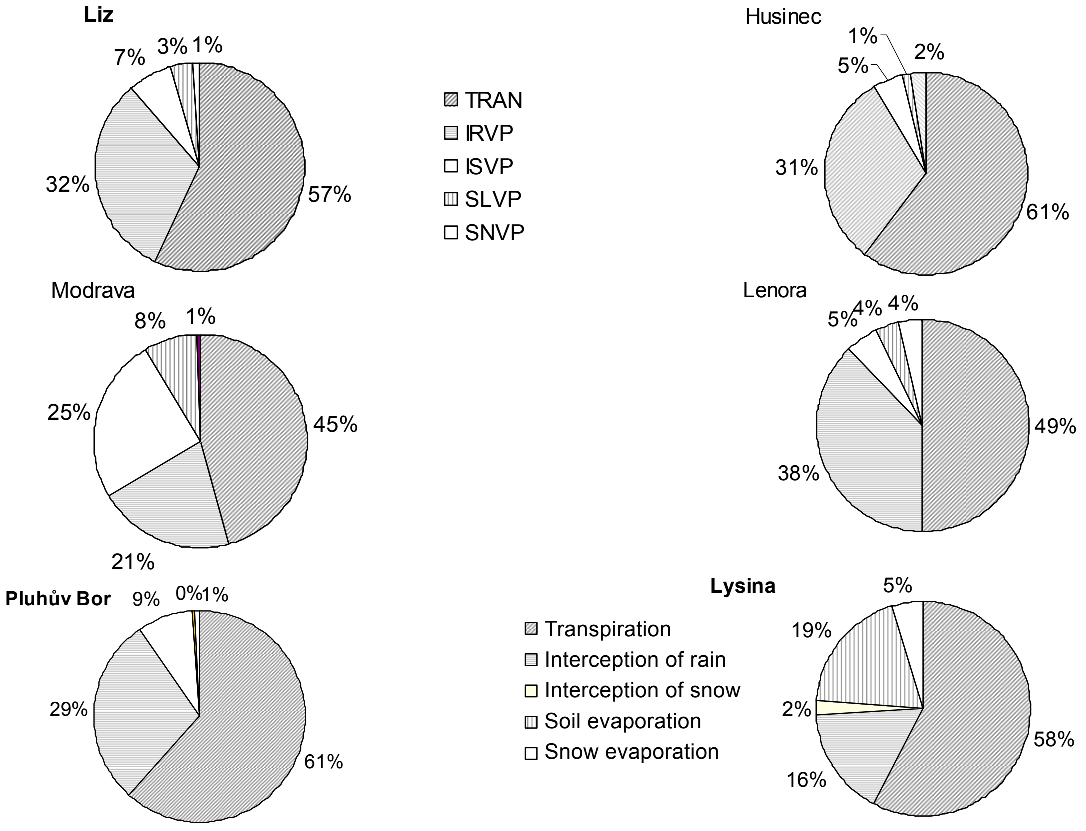

Figure 5. Parts of evapotranspiration demand: transpiration (TRAN), interception (IRVP, ISVP), and evaporation (SNVP, SLVP) as the outputs of BROOK model

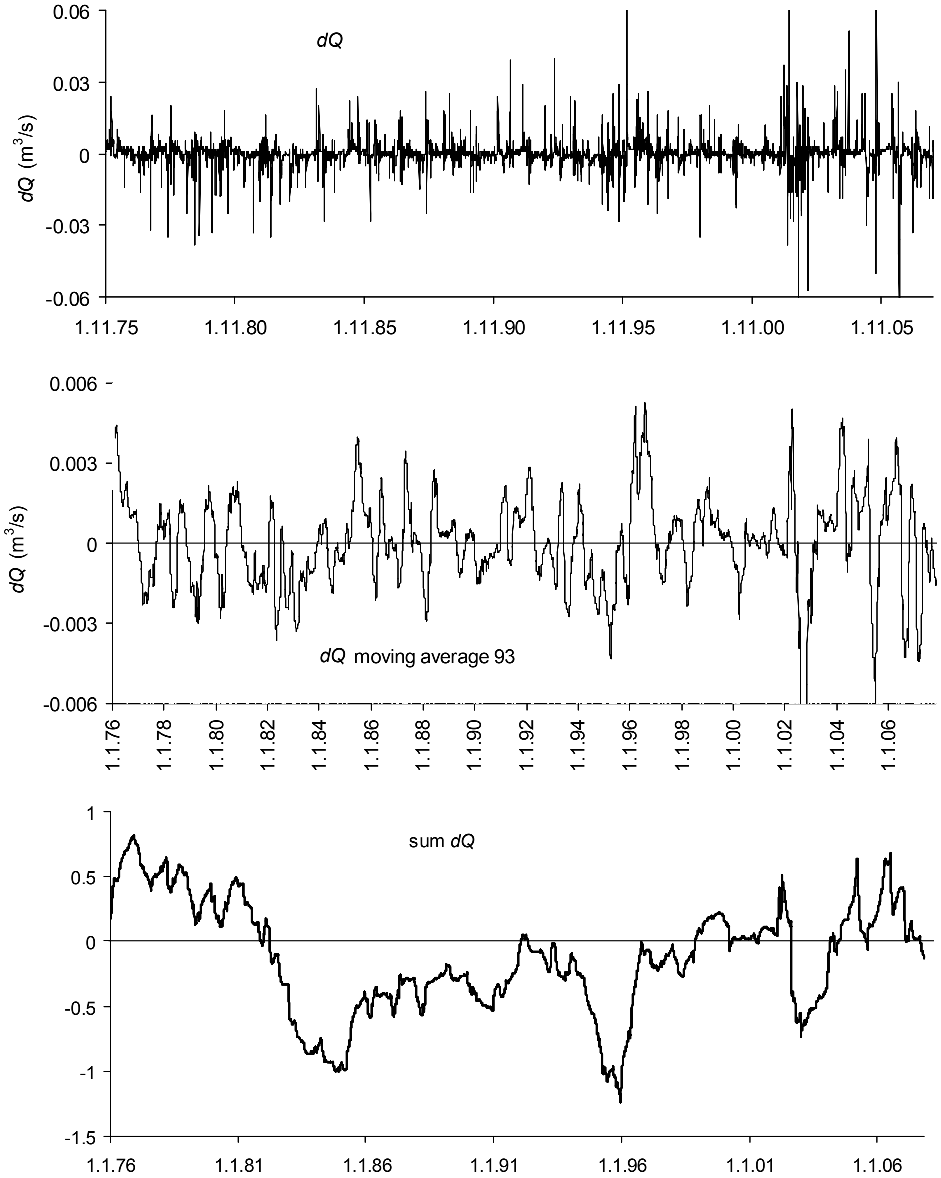

Figure 6. The obtained differences $dQ = Q_{\mathrm{obs}} - Q_{\mathrm{sim}}$ and sum dQ were used for calibration of the SAC-SMA model at the Liz catchment

duction and the proportions of the evapotranspiration demand components as the simulation output are compared for several catchments in Figure 5. Three close and relatively large mostly forested hilly catchments are included there, in which a sudden forest decline, caused by bark beetle outbreak, has led to a decreased transpiration mainly in the Modrava catchment. The values represent the outputs of simulation using BROOK model. Moreover, another results of this modelling are the examples of the annual course of the evaporation demands presented in Figure 10, which shows the variability of evapotranspiration for the assumed stable vegetation cover.

The prevalence of transpiration in a majority of catchments is visible in comparison with other components of the evapotranspiration process. In the Lenora basin with substantial agricultural areas, the rain interception is significant while in the mostly forested hilly Modrava the snow interception creates an important component of total evapotranspiration in this forested hilly basin. Figures 5 and 10 seem to indicate that the evaporation from the soil could be significant even in the basins with coniferous forests.

The differences between the observed and simulated discharges $dQ = Q_{\mathrm{obs}} - Q_{\mathrm{sim}}$ are presented in three figures for several catchments, where

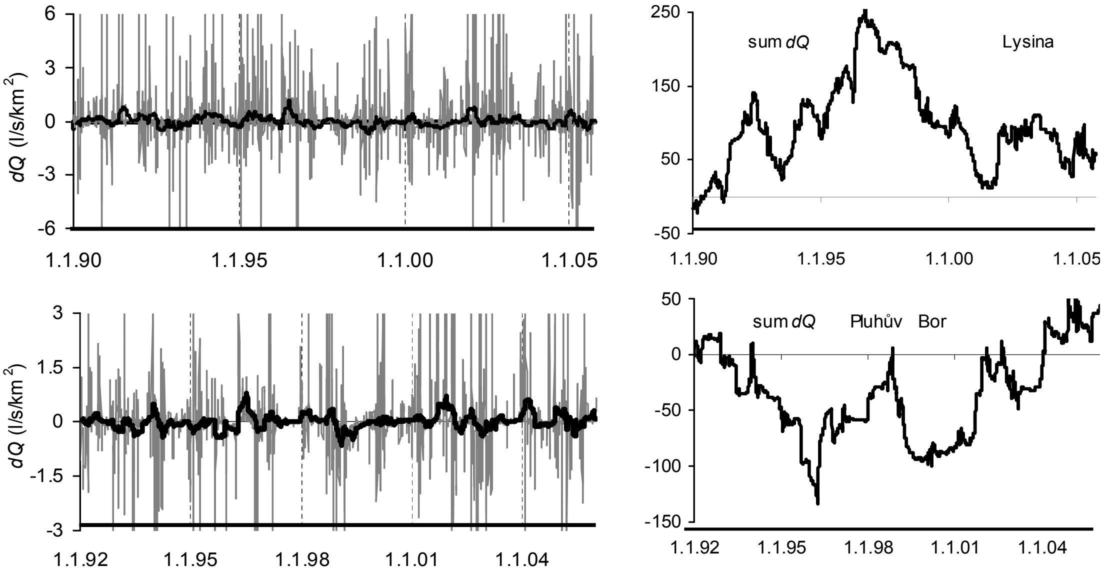

Figure 7. Differences $dQ = Q_{obs} - Q_{sim}$ and sum dQ of the Lysina a Pluhův Bor catchment

the accumulated differences (sum *dQ*) are mostly displayed, which can provide another view on the possible tendency. As examples of the problems encountered, the following specific changes in the evaluated basins can be mentioned:

– Figure 6 (Liz catchment) shows fluctuations in *dQ* differences and namely in the sum *dQ*, which occurred probably due to the instability of the stream channel after the extraordinarily large flood in the year 2002, due to the changes in water level monitoring in the year 1993. It could be due partly also to the differences in the forest cover damage indicated in Figure 11.

– Figure 7 represents the results for Pluhův Bor and Lysina catchments (Hruška & Krám 2003). This figure indicates, by the accumulated differences (sum *dQ*), that diverse forest damage caused by acid atmospheric deposition occurred in these geochemically contrasting but otherwise paired catchments, situated near the heavily damaged forests of the Krušné hory Mts.

– Figure 8 (the Beskydy Mts catchments) presents the effects of scheduled deforestation, i.e. a greater discharge, but in the recent period is it possible to notice again a decrease of discharge, after interrupting the deforestation.

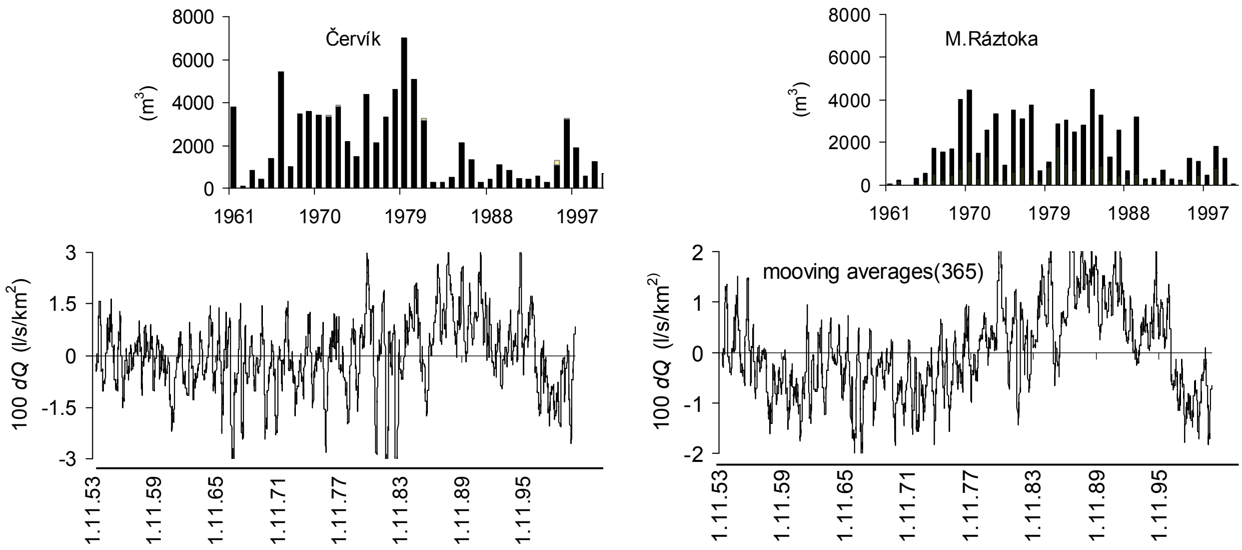

Figure 8. Volumes of wood cutting and differences of discharge $dQ = Q_{obs} - Q_{sim}$ smoothed with m = 365 days for the Červík and Malá Ráztoka catchments (Beskydy Mts)

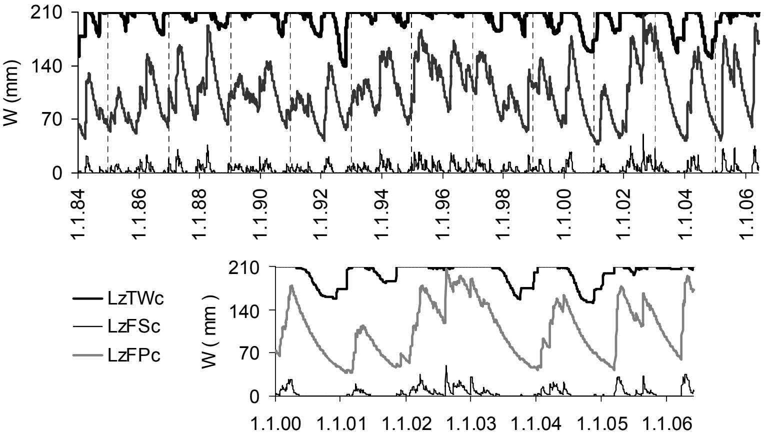

Figure 9. Groundwater storage variability in the Liz catchment simulated by the SAC-SMA model

The outputs for the Husinec Reservoir basin, where the comparisons of SAC-SMA model and BROOK model were prepared, have shown a similar tendency which indicates that the runoff has increased only temporarily after a stationary period. It is probably due to the transient extended arable areas and partly due to the forest damage caused by the insect outbreaks, similarly as it has occurred in the near Liz and Lenora catchments.

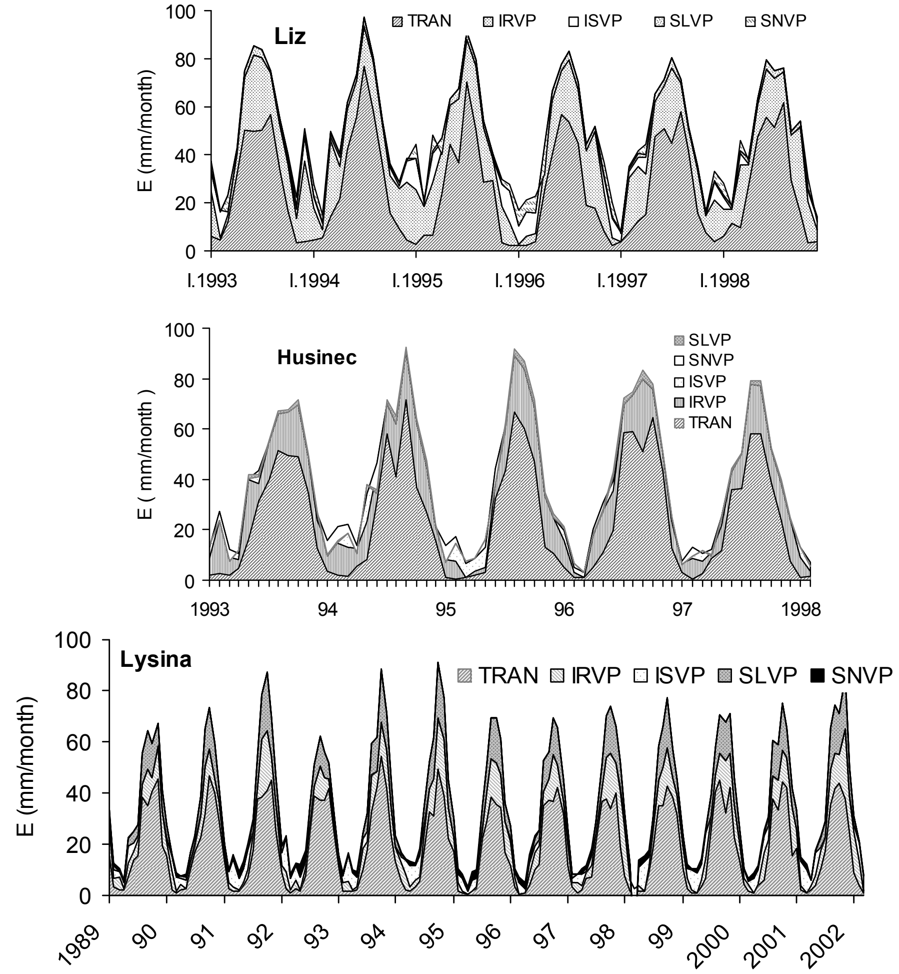

Figure 10. Comparison of evapotranspirations from rainfall–runoff simulation with the BROOK model in the Liz (upper part) and Husinec (central part) catchments and long term variability in the Lysina catchment (bottom part)

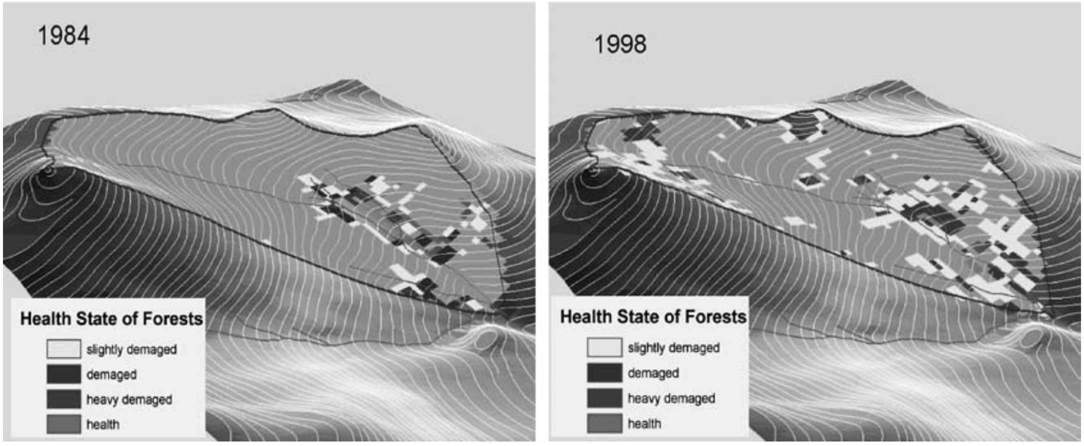

Figure 11. Forest damage in the Liz basin evaluated using satellite images

The long term variability in the slow groundwater storage is illustrated in the upper part of Figure 9 showing the output of SAC-SMA model for the Liz catchment in the period of 1984–2007 with three components of the sub-surface water (LZTWC – Lower Zone Tension Water Content; LZFPC – Lower Zone Free Primary Content; LZFSC – Lower Zone Free Supplementary Content).

It may be noticed that the periods of the greatest deficits in the Tension Zone and in the Free Primary Zone may be very remote, i.e. hydrological and agricultural drought periods could be asynchronous. This is a meaningful phenomenon for the evapotranspiration evolution. The lower part of Figure 9 shows the seasonal characters of the water content in the Tension Zone and in the Supplemental Free Zone, which might be significant also for evaporation.

The comparison of some time intervals in Figures 9 and 10 permits to infer that the oscillation in the soil moisture affects the variability of evapotranspiration or that mutuality exists between these phenomena.

Figure 12 illustrates the diverse values of evapotranspiration demand as identified in the implementation of the SAC -SMA model for separate time intervals of observation in the Liz catchment, which likely indicates the role of the forest cover change.

CONCLUSIONS

The intention should be to decrease the uncertainties due to the annual cycle of climatic conditions in the evaluation of appearing natural and/or artificial changes of the runoff. The results suggest that an improvement of the runoff simulation could be reached by a more precise evaluation of the evapotranspiration demands as the variability of the water regime in the catchments studied is influenced by the changes of the vegetation cover in the annual cycle, but also

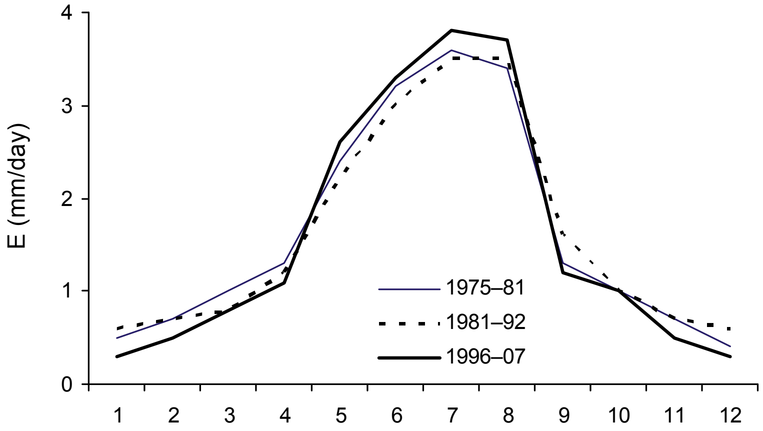

Figure 12. Mean monthly evapotranspiration demands in the Liz catchment in different periods

by its development in the span of decades. The simulations of the rainfall-runoff process are useful for pursuing the possible role of this land use. The differences between the observed and simulated flows in the available period can be considered as a proper tool for the assessment of changes.

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