Long-term Trends of Rainfall and Runoff Regime in Upper Otava River Basin

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Abstract: The floods experienced recently in the Czech Republic gave rise to numerous discussions over the changed environment and related potential impacts on the rainfall and runoff processes. The main aim of our research project was to determine long term trends of rainfall and runoff regime in Otava River basin. The rainfall-runoff analyses using both the single and double mass curves over the period of the hydrologic observations were taken as a basic method. Beside mean discharge, precipitation, snow and air temperature trends, analysis of land cover change and human impact on the river network and drainage areas development were applied too. The greatest deviations were widely observed in the period between the 2nd half of the seventies and in the 1st half of the eighties. It has been related to the one of repeatedly coming rather humid episodes and correspond to major human influences on the river network. The whole system came slowly back to its initial condition in the early nineties. Standard statistical testing methods were applied to confirm the trends. The Wilcoxon single and paired samples test, and furthermore the Mann-Kendall non-parametric test were used. Trend detection using both tests also confirmed a different development of the discharges and precipitation regime in the Ostružná and upper Blanice River basins in the period 1975–1982. The runoff trend deviation has been related to the nature and human factors, mainly to current climatic changes and changes of landscape retention potential.

Keywords: trend analysis; rainfall; runoff; climate change; human impact; the Otava River basin; Czech Republic

Detection of changes in long time series of hydrological data is an important and difficult issue, of increasing interest being fundamental for planning of future water resources and flood protection. Traditionally, design rules are based on assumption of stationary hydrology, resulting in the principle that the Past is the key for Future, which has a limited validity in the era of global change (Kundzewicz & Robson 2004). River discharges may have changed due to a range of human activities, for example river network modifications, land use changes, urbanization, dams building. Another dynamic factor is the climate system. The Earth's climate system has changed considerably since the preindustrial era. The global surface temperature rise of 0.6 ± 0.2°C over the 20th century was greater than during any other century over the last 1000 years (Kundziewicz & Robson 2004). Extreme hydrological events – floods and droughts – have become destructive factor over the globe.

The great floods experienced in 1997 and 2002 in the Czech Republic gave rise to numerous discus-

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sions over the changed environment and related potential impacts on the rainfall and runoff processes. Besides climate change, attention is being drawn to human influence. The Czech landscape has developed in a specific way, which differs from region to region in terms of the intensity of anthropogenic intervention into water balance. Not even mountain and foothill areas have escaped such changes.

The impact of human activities on runoff regimes has been proven by a number of experimental studies from various parts of the world, including several from the Czech Republic. An example of this is the long-term research in the experimental water basins concentrated on monitoring the influences of forest and deforestation (Válek 1953; Švihla *et al.* 1992; Kříž 1981; Jařabáč & Chlebek 1984; Blažková & Kolářová 1994). The studies by Kulhavý (1999) revealed the ambiguity of the results on surface runoff in respect to forest age and species. A higher and less balanced outflow was observed in agriculturally cultivated areas (Föhrer *et al.* 2001; Klöcking & Haberlandt 2002; Robinson *et al.* 2003). Another problem is drainage, which affects on average up to 25.5% of farmland in the Czech Republic, the highest rate in Europe. In general, drainage reduces the level of subsurface water and accelerates and increases the outflow average and minimum (Švihla *et al.* 1992). The surface drainage contributes to an increase in the discharge effect during the floods. (Doležal *et al.* 2004). Special attention is paid to urban areas often associated with channelization, water reservoirs construction and taking water from rivers (Goudie 1992; Sochorec 1997; Kaňok 1999; Meyer 2001; Kříž 2003; Kavan 2004).

Detectability of changes in hydrological records described Radziejewski & Kundzewicz (2004), which is one important practical problem in the statistical analysis of long time series of hydrological records. They examine how strong a change (gradual trend or abrupt jump) must be and how long it must take in order to be detected by different tests. Trends and variability of river flow in different world regions also studied Burn *et al.* (2004), Xiong and Guo (2004), Lindström and Bergström (2004).

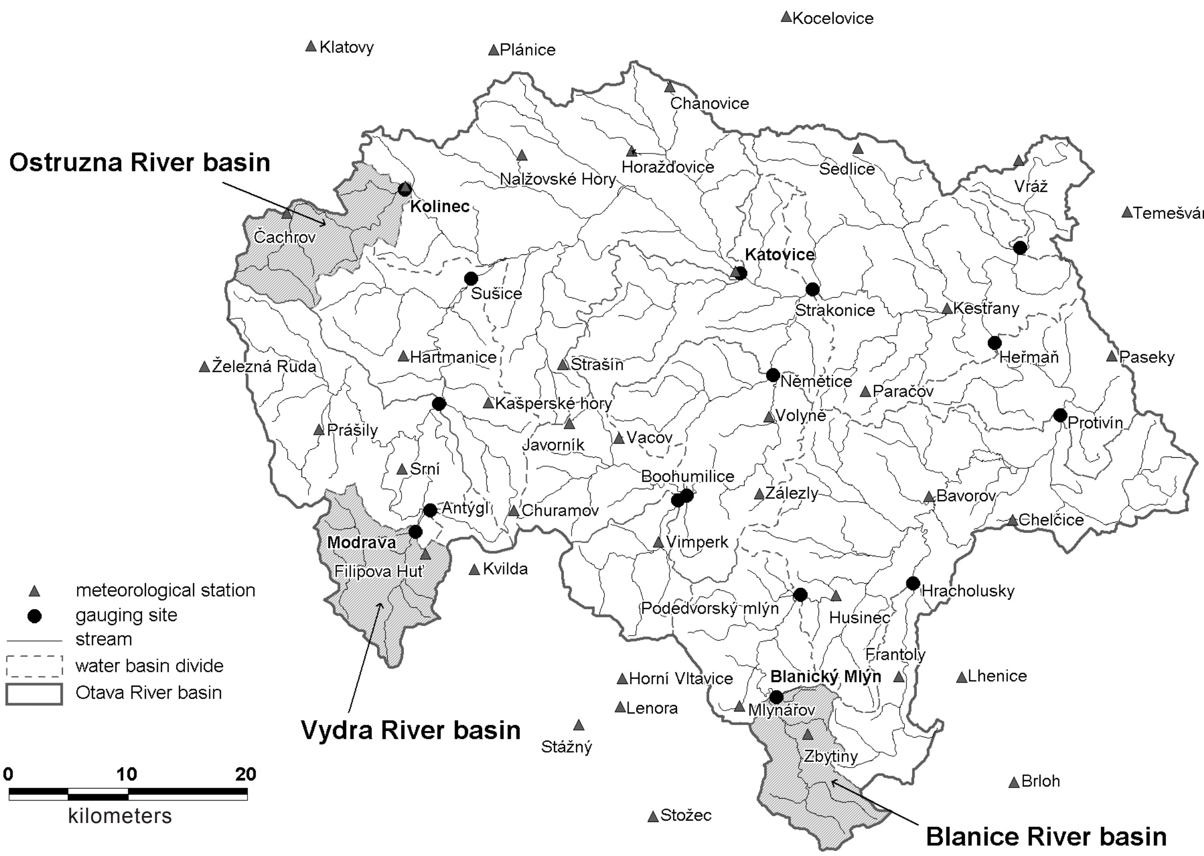

Figure 1. The Otava River basin – location of the study areas: Vydra, Blanice and Ostružná River basins

The main aim of this study is to monitor and try to explain changes in the development of the rainfall-runoff relationship in three water basins situated in the Otava River spring area: the Vydra, the Ostružná and the Blanice River basins in the Czech Republic (Figure 1). The selection of tree small water basins was based on the previous statistical study, which covered analysis of 16 gauging sites and 42 meteorological stations in the whole Otava River basin (area of 3800 km^2) (Kliment & Matoušková 2005). The selected water basins represent areas of diverse land use with different levels of anthropogenic intervention in the runoff regime. All three basins played an important role during the initial formation of outflow during the catastrophic floods in Czech Republic in August 2002 (Langhammer *et al.* 2003).

Characteristics of selected case study catchments

The upper stream of the Ostružná River drains the high part of the Šumava Mountains (the Kochanske plains). Most of the basins belong under the Šumava foothills. The highest place is situated at 1177 m, the lowest part at 528 m in the gauging site Kolinec. Metamorphic Pre-Cambrian rocks, orthogneisses and paragneisses, prevail in the subsoil. Cambisols merge into cryptopodsols and podsols at higher altitudes. The landscape is used for agriculture. The forestation reaches 40.7%, arable land accounts for only 17.2% in the present. The countryside settlement is typical for this area (Table 1).

The Vydra River drains the high part of the Šumava (Kvildské Plains). The highest place of the basin is situated at 1373 m and the lowest at 935 m in the gauging site Modrava. Metamorphic Pre-Cambrian rocks with biotic granites prevail in the subsoil. Crypto-podsol and podsol are characteristic, hydromorphic soils are also common. The basin is a natural forested landscape with the occurrence of peat bogs. The basin is situated in the Šumava National Park.

The Blanice River drains the high part of the Šumava (Boubínsko-želnavské Mountains). The highest place is situated at 1228 m and the lowest at 743 m in the gauging site Blanický Mlýn. Metamorphic Pre-Cambrian and Palaeozoic migmatites prevail in the subsoil. The most common are cryptopodsols. The landscape is covered by forest (66.7%) and meadows (27.7%). At present, a cattle breeding is typical for the area.

METHODS AND DATA SOURCES

The methodology of the research comprises analytical and synthetic procedures. The basic analytical procedure can be regarded as the analysis rainfall and runoff trend regime supplemented by an analysis of air temperature and snow parameters relationships. The method of simple and double mass curves was used as the main method for the evaluation of the trend in outflow values development in the selected water basins. Significant deviations from the linear course together with sudden variations can indicate changes in the runoff regime. Besides simple mass curves for basic discharge characteristics (daily (Qd), monthly (Qm) discharges and daily (Hd), monthly (Hm) precipitation, double mass curves for annual cumulative precipitation and discharge values were plotted for a better identification of changes in the trend. The analysis itself was preceded by the necessary step of homogenizing the precipitation data. Thiesen polygons method was used first to derive the precipitation in the water basins. Subsequently, a method taking into account the altitude was used (Kavan 2004). Standard statistical testing methods were applied to detect the trends, as well: the Wilcoxon single sample as well as paired samples non-parametric test, and furthermore the Mann-Kendall non-parametric test (Mann 1945;

Table 1. Basic rainfall and water runoff characteristics of the test water basins

DBNr	Gauging site	River	Monitoring from	A (km^2)	P* (mm)	Q_a (m^3/s)	q_a (l/s/km^2)	φ*
1350	Modrava	Vydra	1931	93.41	1327	3.18	35.2	0.84
1390	Kolinec	Ostružná	1949	92.42	916	1.20	13.1	0.45
1450	Blanický Mlýn	Blanice	1953	85.21	760	0.79	9.2	0.38

*data from 1961–2002, other from the beginning of measurement

DBNr – database number; A – area, P – precipitation; Q_a – discharge, q_a – specific outflow, φ – runoff coefficient

Kendal 1975; Lindström & Bergström 2004; Xiong & Guo 2004).

The development of runoff in the given water basins was further supplemented by an analysis of the development of air temperature and snow characteristics (number of days with snow cover; average and maximum snow cover depth). Trends were described in the form of 5-year moving averages of monthly, annual and seasonal values. The basic source of input outflow and climate values was the Czech Hydrometeorological Institute (CHMI) database.

Following the analysis of the trends in runoff, rainfall and air temperature regimes, analysis of changes in landscape use, river network training and land drainage were carried out. The results were related to the duration of the water level monitoring in the given water basins, i.e. over approximately the last 50 years. Changes in land use were assessed based on cadastre register (Bičík *et al.* 2003) and with the help of database CORINE Land cover (1992, 2000). The human impact on the river network was evaluated based on Water Management Maps (WMM) 1:50 000 and on materials provided by the Agricultural Water Management Authority (AWMA). Land drainage and its development over time was derived from map documents with a scale of 1:10 000, as provided by AWMA. The existing analogue and digital databases, as well as the terrain research itself, were used.

Analysis of rainfall-runoff regime trends

The method of simple mass curves was used for the identification of significant changes in the water runoff regime. A wide variety of the profiles in the Otava River basin monitored in the 2nd half of the seventies and in the 1st half of the eighties showed an obvious outflow increase which must have been related to the beginning of one of the repeatedly coming rather humid episodes. The winter-season proportion of the outflow started increasing in this period of time, and this trend, barring some exceptions, has continued until now. It is interesting, that the system as a whole came slowly back to its initial condition in the early nineties. The greatest deviations were widely observed within the fairly small river basins in the foothill of the Šumava Mountains, but rarely were registered within the mountain river basins on the upper stream and on the down stream of the Otava River.

Considerable changes were identified in the Ostružná River basin, where an increase in runoff was recorded in the period 1975–1980. A less considerable change in the trend in the period 1975–1982 was also confirmed on the Blanice River. On the contrary, on the Vydra River no changes in the water runoff regime were identified (Figure 2). Double mass curves were constructed of annual discharge and rainfall values, which best

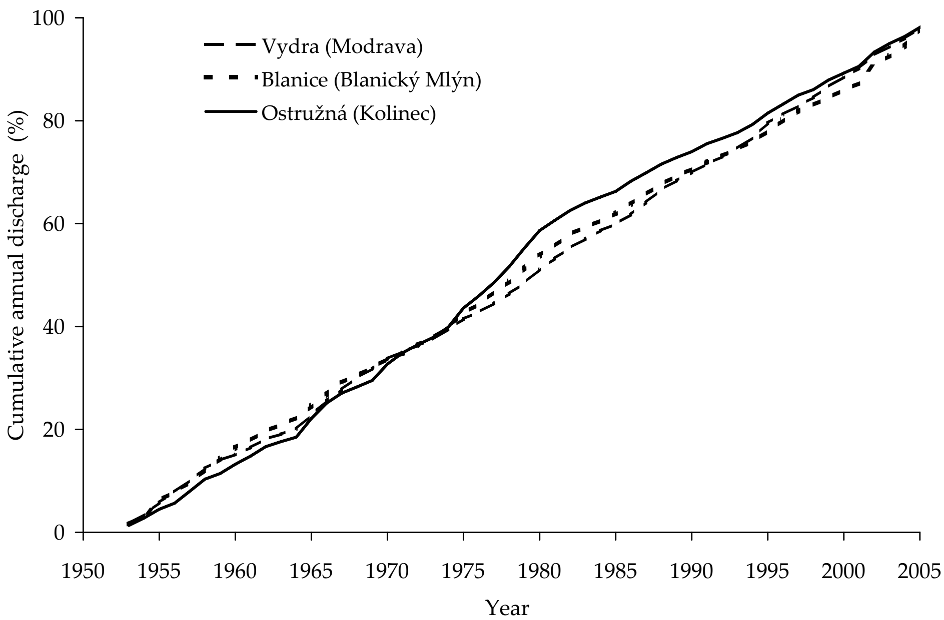

Figure 2. Simple mass curves of daily discharge values for gauging sites: Modrava, Kolinec, Blanický Mlýn (source: CHMI)

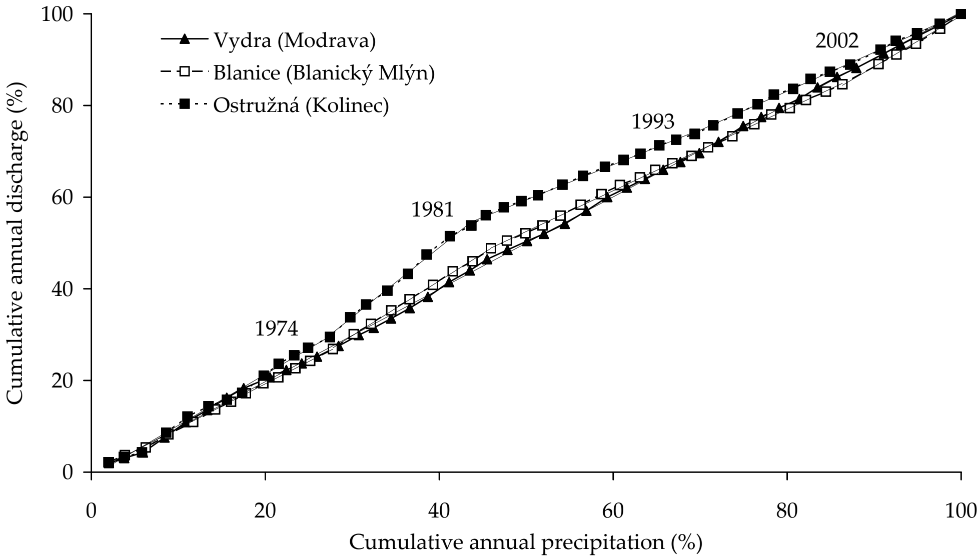

Figure 3. Double mass curves of annual precipitation and discharge for gauging sites: Modrava, Kolinec, Blanický Mlýn

describe the identified changes in water runoff. The results confirmed the findings of previous analyses (Figure 3).

The Wilcoxon single sample as well as paired sample non-parametric test was used to verify the differences between two independent sets for time-delimited groups of yearly discharges (*Qr*), and further of yearly precipitation values (*Hr*). The groups were delimited based on sudden changes determined in the time series development of the discharges for the studied river basins, obtained by the mass curves analysis, and they included three periods: 1967–1974, 1975–1982, and 1983–1990. While no differences in the discharges sets under evaluation were shown in the Vydra River basin, certain differences were shown in further river basins, where the test criterion for the period 1975–1982 was lower or equal to the critical value for the Wilcoxon test for $\alpha = 0.05$, thereby leading to refusal of the zero hypothesis, stating no difference between the sets, on this level. Significant statistically proven differences were shown both compared to the previous period as well as to the subsequent period. No differences between the periods were shown in any of the river basins for the precipitation amounts. When using the paired test (observing of differences among river basins in the given time periods), the differences were not so prominent anymore, and they were shown only in the discharges of Vydra × Ostružná Rivers (1975–1982:1983–1990, $W_{0.05}(8) = 2$), Ostružná × Blanice Rivers (1975–1982:1983–1990, $W_{0.05}(8) = 0$). The results confirmed the exceptional character of the discharges development in the Ostružná River basin. In relation to further river basins under comparison and the periods evaluated, especially the decrease of discharges values for the period 1975–1982 was manifested statistically.

The Mann-Kendall non-parametric test (Mann 1945; Kendall 1975; Lindström & Bergström 2004; Yue & Pilon 2004) was used for trend detection, as well, applied to the time series of average

Table 2. The Mann-Kendall correlation matrix values for *Qm* (average monthly discharge), *Hm* (average monthly precipitation)

Period	Ostružná River	Vydra River	Blanice River
1962–2002	0.349	0.717	0.355
1962–1974	0.608	0.790	0.607
1975–1982	0.200	0.793	0.224
1983–1990	0.644	0.632	0.680

yearly discharges (*Qr*) and yearly precipitation (*Hr*), and furthermore tested on monthly discharges (*Qm*) and monthly precipitation (*Hm*). The time series of *Qr*, *Hr* were tested at first for the period 1962–2002. Based on the calculation of the Kendall correlation matrix vaue, the dependence trend in the Vydra River basin and in the Blanice River basin was identified. Furthermore, selected segments of the time series were studied based on sudden changes detection in their development from previous analyses. In the case of the Vydra River basin, the dependence trend was found in all the three periods under observation. As for the Ostružná and Blanice River basins, the dependence trend was identified only in the two periods 1962–1974 and 1983–1990. In the period 1975–1982 when a substantial change occurred in the course of single and double mass curves, no trend was identified, on the contrary. The model river basins were further subjected to analysis using the so-called seasonal Mann-Kendall test (Dennis & Lonna 2006), based on *Qm* and *Hm*. The Mann-Kendall correlation matrix values calculated are shown in Table 2. The correlation was confirmed in all the periods observed in the Vydra River basin. Dependence thus exists between average monthly discharges and precipitation. Furthermore, correlation was found in the periods 1962–1974 and 1983–1990 in the Ostružná and Blanice River basins. On the contrary, it was not identified in any of these two river basins for the period 1975–1982. Trend detection using the Mann-Kendall test thus also confirmed a different development of the discharges and precipitation regime in the Ostružná and upper Blanice River basins in the period 1975–1982.

Seasonal runoff changes within a year were assessed based on the development of the percentage share of runoff both in individual months and individual seasons. What is characteristic for the water runoff regime in the last 50 years is the considerable increase (of more than 5%) in the winter months, particularly after 1975. On the other hand, we can see a gradual decrease in the runoff in summer months for the same period, with exception floods in August 2002. The largest increase is in December and the largest decrease is in July. Monthly and seasonal shares of precipitation remain approximately the same in the given seasons without perceptible trends or deviations (Figure 4). The Vydra River basin does not display any significant changes in its water runoff distribution.

Air temperature and snow parameters analysis

Changes associated with global warming have been frequently discussed in the last few decades. Snow and air temperature parameters were compiled from three climate stations. The stations are at different altitudes in the Šumava Mountains and foothills: Churáňov, Kašperské hory and Klatovy

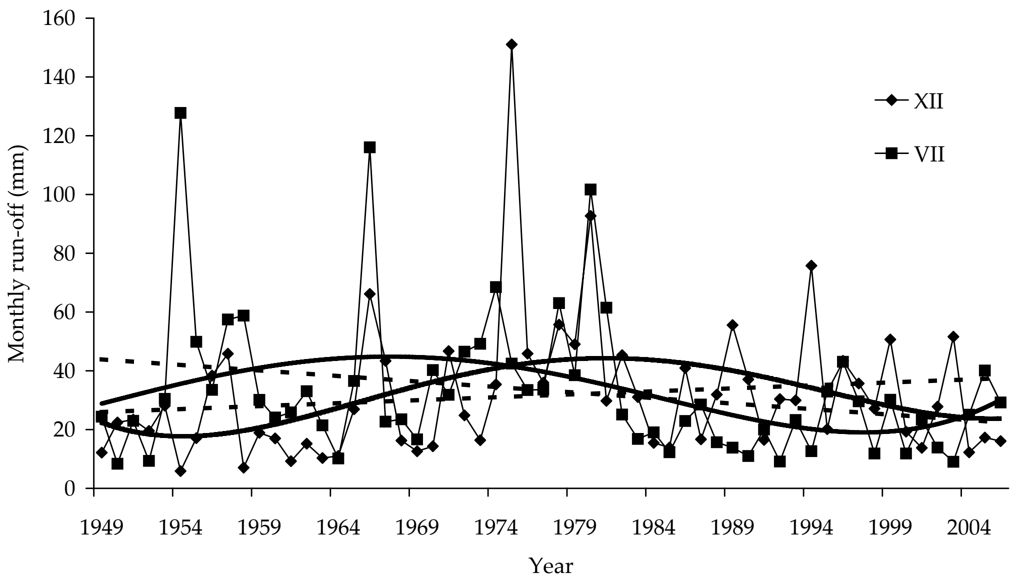

Figure 4. Trends of run-off regime in December and July for gauging site Kolinec; linear and polynomic trends were used

Table 3. Mean annual air temperature and snow cover characteristic

Climatic stations	Klatovy	Kašperské Hory	Churáňov
Altitude (m)	430	737	1118
Mean air temperature (°C)	8.1	6.2	4.4
Mean precipitation (mm)	607	830	1098
Mean snow cover depth (cm)	6.6	14.3	39.1
Mean maximum snow cover depth (cm)	17.5	39.3	97.5
Mean numbers of day with snow cover	49.9	88	143.9

(Table 3). The Klatovy station has the longest monitoring sequence, allowing air temperature characteristics to be related to the beginning of the last century. By comparing average values for the periods 1901–1950 (Vesecký *et al.* 1961) and 1951–2003, a rise in temperature from 7.6°C to 8.1°C was identified. The last 50-year monitoring period shows a significant rise in air temperature in the 1980s and, in particular, from the beginning of the 1990s. Certain signs, particularly during the winter season, can already be observed in the 1970s. The biggest rises in air temperature are observed in February and August and also in January, May and March. The situation is depicted in Figure 5. Similar trends were observed for all three stations.

The average number of days with snow covers for the period 1950/51–2003/04 is practically the same as the average value for the period 1920/21–1949/50 (about 50). A certain reduction in the number of days of snow cover can be seen from the 1970s and, more significantly, during the 1990s. At the same time, despite the apparent increase in winter precipitation, the average snow cover depth was reduced by almost a half for comparable amounts of winter precipitation (Figure 6).

The period of the identified increase in water runoff (1975–1982) can be characterized as average from a temperature perspective, with a higher average snow cover depth and a higher number of days with snow cover. The significant increase in spring and summer temperatures from the beginning of the 1980s could then contribute to the reduction in water runoff, particularly in the summer months.

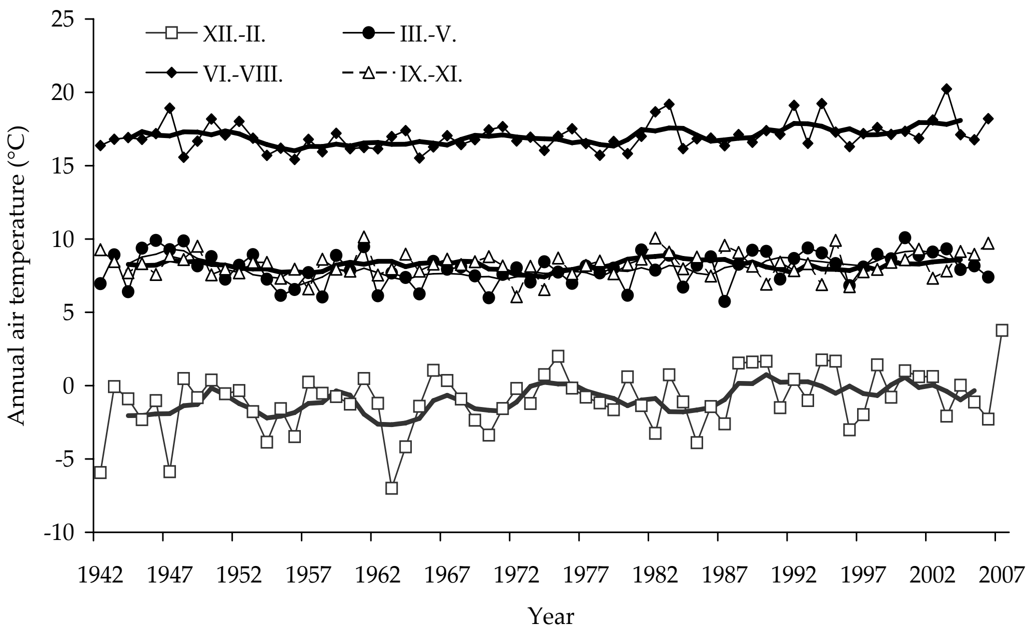

Figure 5. Development of mean air temperature in season periods, station Klatovy; 5-years moving averages were used (source: CHMI)

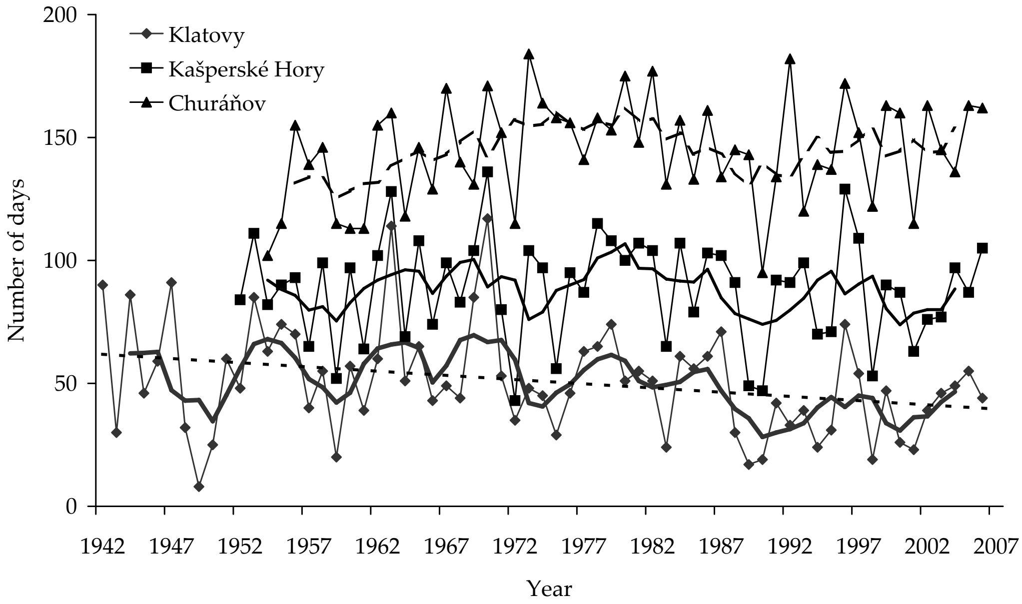

Figure 6. Annual snow cover depth in winter period (XI–IV) for climatic stations Klatovy, Kašperské hory and Churáňov; 5-years moving averages were used (source: CHMI)

Land cover changes analysis

The long-term trends of the changes in the mountain and foothill landscape in the Šumava can be monitored based on statistical data from cadastre unit records. The landscape changes reflect changes in political and economic conditions. According to Bičík *et al.* (2003), which compared the structure of land use in the periods 1845–1948–1990, there was a significant decrease of arable land at higher altitudes (above 800 m above sea level) after 1948. The decrease in arable soil was compensated by the growth of forest. The amount of arable land at lower altitudes remained approximately constant. However, the structure of the landscape changed significantly during the period of socialistic agriculture mainly during 1960s–1980s. Introduction of large-area farming led to the loss of the

Table 4. Land cover changes (in %) for study water basins (source: CORINE)

Units	CORINE land cover	Ostružná (Kolinec)		Blanice (Blanický Mlýn)		Vydra (Modrava)	
		1992	2000	1992	2000	1992	2000
112	discontinuous urban fabric	0.9	1.3	0.3	0.3	0.0	0.0
211	non-irrigated arable land	**45.7**	**17.2**	5.7	0.3	0.0	0.0
222	fruit trees and berry plantations	0.3	0.0	0.0	0.0	0.0	0.0
231	pastures	**4.7**	**30.2**	22.3	16.9	4.2	5.7
243	land principally occupied by agriculture	11.1	10.1	6.7	3.9	0.0	0.0
311	broad-leaved forest	0.0	0.5	0.2	0.8	0.0	0.0
312	coniferous forest	32.5	37.9	**41.9**	**61.2**	65.2	58.1
313	mixed forest	1.7	1.2	7.2	2.3	0.3	1.0
321	natural grassland	0.0	0.0	3.0	10.8	1.1	1.1
324	transitional woodland shrub	3.0	1.7	12.6	3.4	29.2	34.2
Total area		100.0	100.0	100.0	100.0	100.0	100.0

Bold printed values mean the most important changes in the land cover

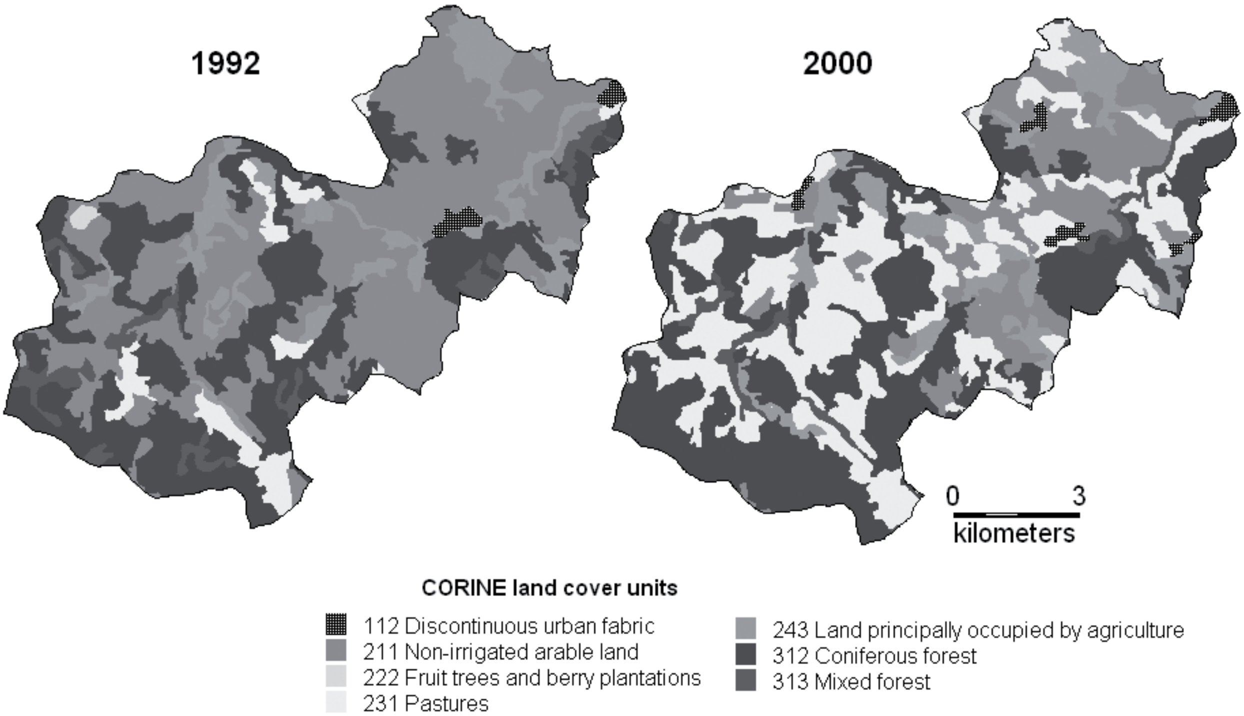

Figure 7. Land cover changes in the Ostružná River basin (source: CORINE Land cover)

stabilizing elements in the landscape. Intensive agriculture was accompanied on the extensive land drainage of swamped areas and the straightening of smaller rivers. Such changes could negatively affect the outflow characteristics. As a result of state subsidies, the Šumava foothill areas have been extensively grassed over after 1994 (Table 4).

The river basins monitored are different in terms of the land use and their development over the last 50 years. The Ostružná river basin, where arable land used to cover over 45% of the area in the past, has experienced the biggest changes. In the 1990s most of the previously farmed land has been grassed over (Figure 7). Similar changes together with the forestation have also occurred in the Blanice River basin. Such changes could contribute to the increase in the landscape retention and to the reduction in average and minimum values of surface runoff.

River network training and land drainage analysis

River training and amelioration measures represent other significant anthropogenic intervention in the river basins. The first initial modifications of river network in 19th century did not represent significant interventions into the river habitat, i.e. river network lengths did not experience any significant changes. Natural materials were mainly used for the alterations. More significant impact into the river network has occurred in connection with flood protection, urbanization and amelioration measures. The main river alterations were carried out between 1960 and 1987 in connection with the drainage of farmland in the Ostružná and Blanice River basins. The highest level of channelization is displayed in the Ostružná river basin, where the tributaries of the main river are chiefly affected (21%). The river channels were straightened deepened and stabilized using concrete prefabricated elements. The Blanice River basin has a significantly lower level of channelized sections (6%) mainly in the Zbytínský Brook basin. No significant anthropogenic interventions to the river network were identified in the Vydra River basin except of forest amelioration in the 19th and 20th centuries (Hais 2004).

The land drainage carried out in connection with intensive agriculture in particular. The first interventions were carried out during the 1960s. The largest growth in the size of drained areas occurred between 1975 and 1982. The total amount of the drainage reaches 829 ha in the Ostružná river basin, i.e. 8.3% of the river basin area (Figure 8).

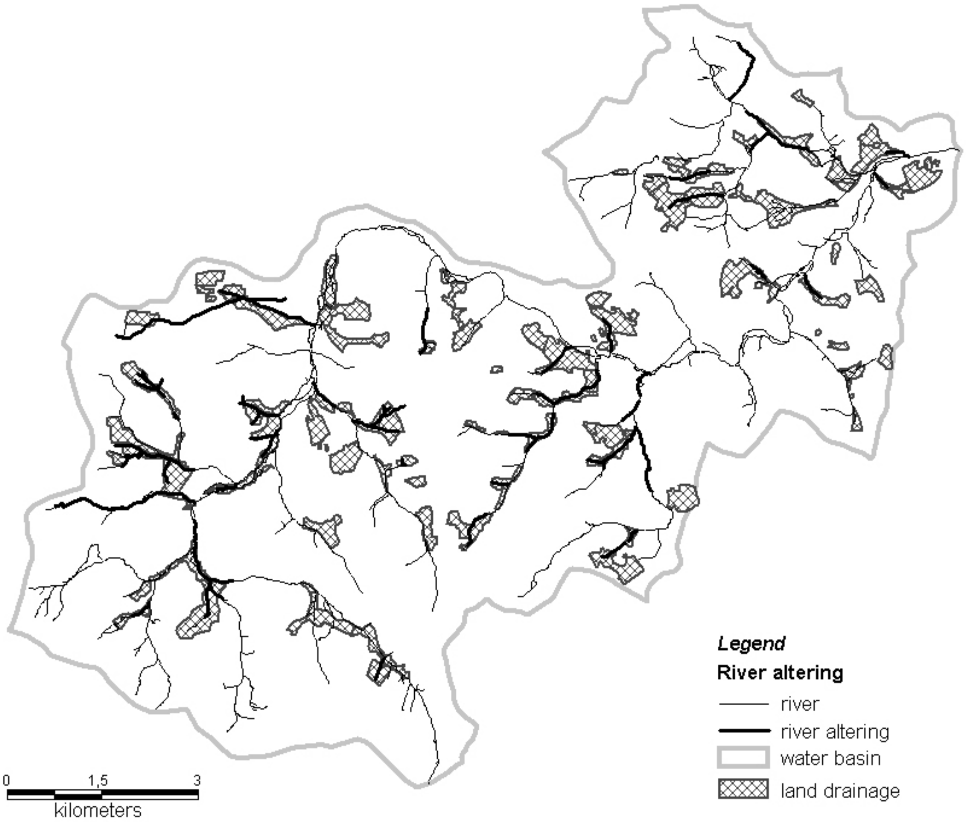

Figure 8. River training and land drainage in the Ostružná River basin (source: AWMA Prachatice)

In the case of the Blanice amelioration measures were applied from the beginning of the 1970s. The largest draining period corresponds with the situation in the Ostružná River basin. The total amount of land drainage reaches 450 ha, i.e. 5.3% of the river basin area (Figure 9).

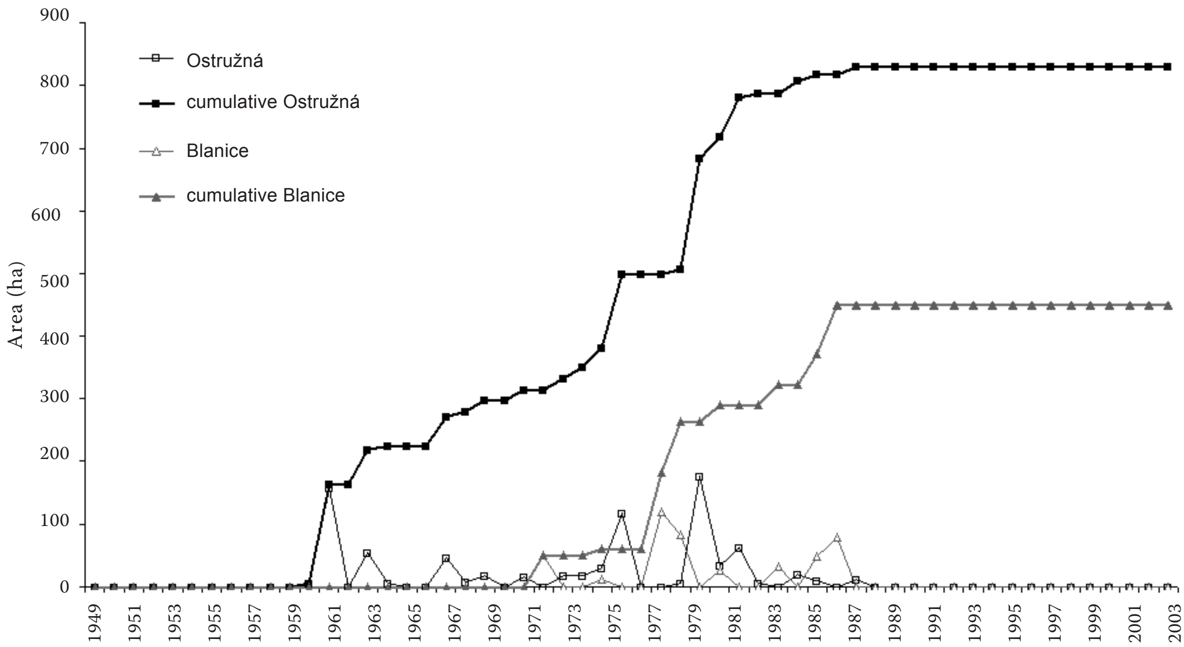

Figure 9. Land drainage in the Ostružná and Blanice River basins (source: AWMA Prachatice)

SUMMARY AND DISCUSSION

An analysis of discharge characteristics shows a continuous period of higher runoff during the period 1975–1982 during both the growing and cold seasons. After 1982, we can see lower or low water runoff values, particularly in growing periods (Figure10).

The period of higher runoff between 1975 and 1982 is connected with a period of higher precipitation. The given period can be described as not completely adequate from the point of discharge values in relation to the precipitation amount. From the end of the 70's there is a clear decrease in and higher fluctuation of precipitation in vegetation period and precipitation increase in cold periods particularly at higher altitude.

In terms of air temperature, the period 1975–1982 is one of below-average and very cold periods. Low average temperature values were mainly observed in the growing periods. Conversely, slightly above-average temperatures were reached in winter period. Looking at the 50-year sequence as a whole, there is air temperatures increase considerably from the beginning of the 1980s and more so during the 1990s, during both summer and winter months.

Above-average depths of snow cover characterize the period 1975–1982. The number of days of snow cover is also above average. In connection with increased temperatures, reduced snow cover depths and the number of days with snow cover can be observed from the end of the 1980s. One of the consequences of these factors is the change in the water runoff distribution during the year in favor of the winter months (from the mid-1970s).

In the period 1845–1990 no significant land cover changes were identified in study water basins. Nevertheless, there were significant changes in the structure of the landscape as a result of the introduction of large-area farming. A signifi-

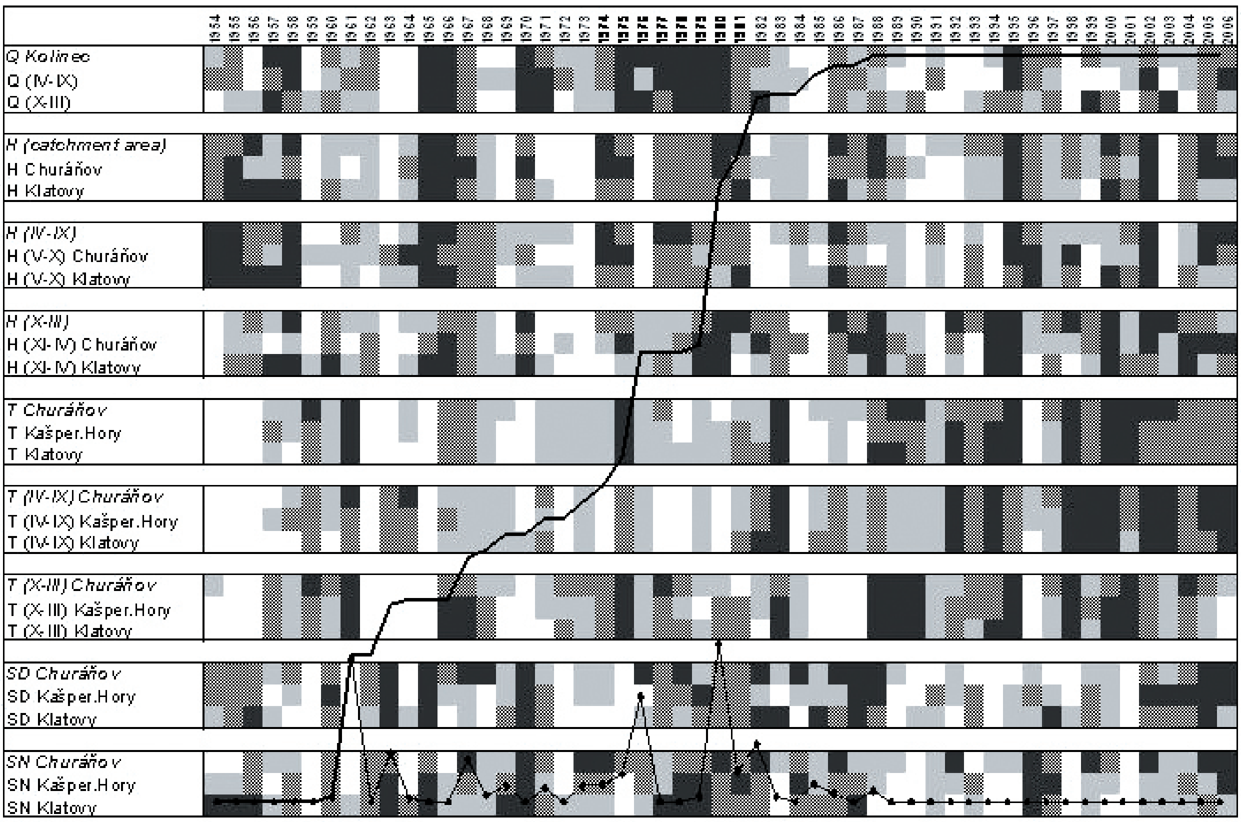

Figure 10. Climate development and increase of land drainage in the Ostružná River basin in period 1954–2006 (source: CHMI, AWMA)

Q: mean discharge, *H*: precipitation, *T*: mean air temperature, *SD*: snow cover depth, *SN*: number of days with snow cover; black colour areas: values > upper quartile, gray dark: < upper quartile, median>, grey light: <median, lower quartile>, white: <lower quartile; graph: thin line: development of land drainage, thick line: development of land drainage (cumulative)

cant reduction of arable land (particularly in the Ostružná River basin) was in the 1990s, which was compensated for by an increase in meadows and forests areas. These changes can be seen as positive in terms of the higher landscape water retention and the evapotranspiration process.

The greatest increase in drained areas occurred between 1975 and 1982, which corresponds with the identified increase in runoff in this period.

CONCLUSION

Through monitoring the runoff and rainfall processes using the method of simple and double mass curves, deviations in the trend of runoff were observed. Out of the three study water basins in the Šumava Mountains and foothills, the largest deviations were seen in the Ostružná River basin, which is used for agriculture. The deviations were less significant in the Blanice River basin. No deviations were found in the naturally forested Vydra River basin. The changes were manifested by considerable increases in the runoff during the 1970s and 1980s, and by a gradual reduction in runoff during the following years. The analysis of runoff and precipitation distribution within a year identified certain links between increase in runoff and one of the periods rich in precipitation. The relatively continuous cold period was manifested by above-average snow cover depth and above-average numbers of days of snow cover. After 1982 and particularly in the 1990s, lower-than-average and low runoff values can be identified; especially during growing periods and particularly in connection with the air temperature increases in the summer and winter months. With regard to the specificity and non-repetition of the identified water runoff trend during the 50-year period, we can assume that, besides natural factors, anthropogenic interventions also played a role. This particularly includes the extensive amelioration measures, river network modification and the construction of drainage systems. The period with the most intensive increase in drained areas corresponds with the increase in water runoff. Conversely, the significant reduction in arable land areas in the last ten years, together with the identified climatic trends, could contribute to the increase in the evapontranspiration. It could cause the overall reduction in runoff. Determining the importance and influence of the factors affecting the water runoff seems to be very difficult.

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