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Runoff Changes in the Šumava Mountains (Black Forest) and the Foothill Regions: Extent of Influence by Human Impact and Climate Change

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Abstract The main aim of our research project was to determine the extent to which the outflow can be influenced by human interventions in three selected water basins in the Šumava Mountains (Black Forest) and its foothills. The rainfall-runoff analyses using both the single-mass and double-mass curves over the period of hydrologic observations were taken as a preliminary methodology. Standard statistical testing methods Wilcoxon and Mann–Kendall non-parametric tests were applied to detect the trends. Besides mean discharge, precipitation, snow and air temperature trends, analysis of land cover change and human impact on the river network and development of drainage areas were also carried out. The greatest deviations were widely observed in the period between the second half of the 1970s and the first half of the 1980s. The whole system came slowly back to its initial condition in the early 1990s. The runoff trend deviation was related to natural and human factors, mainly to current climatic changes, river network modification and changes of land cover.

Keywords Trend analysis · Runoff · Climate change · Human impact · Otava River · Šumava Mt. (Black Forest) · Czech Republic

1 Introduction

The detection of changes in long-time series of hydrological data is an important and difficult issue that is of increasing interest because of its fundamental role in the planning of future water resources and flood protection. Traditionally, design rules are based on the assumption of stationary hydrology, resulting in the principle that the past is the key to the future, which has a limited validity in the era of global change (Kundzewicz and Robson 2004). River discharges may have changed due to a range of human activities, for example, river network modifications, land use

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changes, urbanization, and building of dams. Another dynamic factor is the climate system. The Earth's climate system has changed considerably since the pre-industrial era. The global surface-temperature rise of $0.6 \pm 0.2°C$ over the twentieth century was greater than during any other century over the last 1,000 years (Kundzewicz and Robson 2004). Extreme hydrological events—floods and droughts—have become destructive factors around the globe.

The great floods experienced in 1997 and 2002 in the Czech Republic gave rise to numerous discussions 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. Research is concentrated on monitoring the influence of land-cover changes, mainly deforestation and afforestation processes (Blažková and Kolářová 1994; Huang et al. 2003; Cosandey et al. 2005; Wu et al. 2007; Chaves et al. 2008, and others), and influence of cultivated areas (Föhrer et al. 2001; Klöcking and Haberlandt 2002; Robinson et al. 2003). There is also the influence of subsurface drainage, which affects, on average up to 25.5% of farmlands in the Czech Republic (Švihla et al. 1992; Doležal et al. 2004). Specific attention is paid to urban areas often associated with channelization, construction of water reservoirs, and taking water from rivers (Goudie 1992; Kříž 2003; Meyer 2001; Sochorec 1997). At present, studies often discussed are on land-management changes together with climate changes (Juckem et al. 2008; Huo et al. 2008; Zhang et al. 2008, and others). An assessment of individual runoff influencing variables is required (Hundecha and Bárdossy 2004; Samaniego and Bárdossy 2005). To assess the hydrological consequences of land cover and climate changes, different methods are used: hydrological modelling and statistical procedures including analysis of long-time series of hydrological records. Detection of changes in hydrological records is described in the work of Radziejewski and Kundzewicz (2004). They examined how strong a change (gradual trend or abrupt jump) must be and how long it must take in order to be detected by different methods. There are many studies of temporal trends of hydro-climatic variables and runoff response to climate and land-management changes in different regions of the world (Kothvari and Singh 1996; Gan 1998; Yu et al. 2002; Burn et al. 2004; Xiong and Guo 2004; Fu et al. 2004, 2007a, b; Xu et al. 2004; Lindström and Bergström 2004; Ludwig et al. 2004; Birsan et al. 2005; Chen et al. 2007; Bae et al. 2008, and others).

The main aim of this study is to explain the 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 (See Fig. 1). The selection of the three small water basins was based on the previous statistical study, which covered the analysis of 16 gauging sites and 42 meteorological stations in the whole Otava River basin (area of 3,800 km^2). The selected water basins represent water basins with high quality standard of data monitoring but also 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 the Czech Republic in August 2002 (Langhammer et al. 2003).

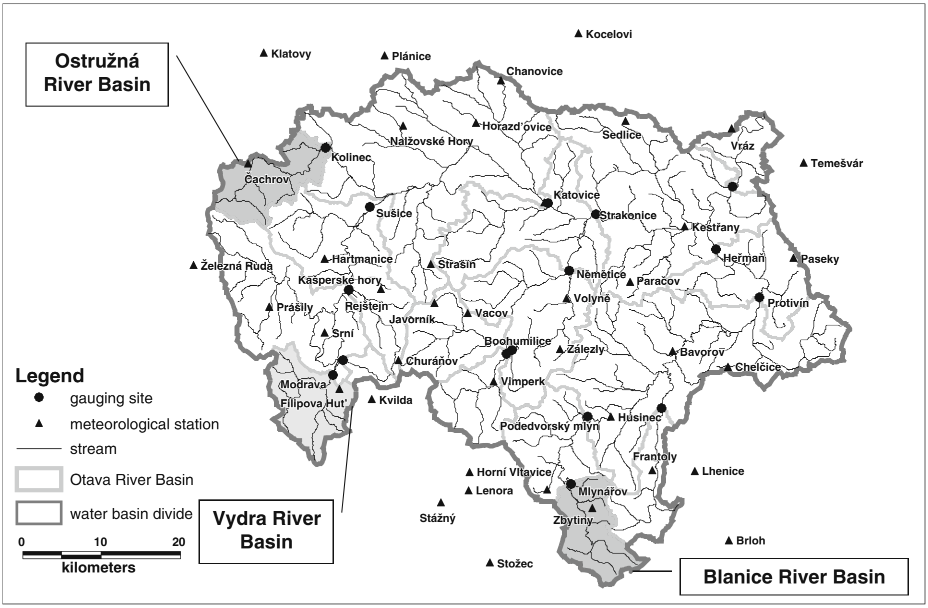

Fig. 1 The Otava River basin—location of the studied areas: Vydra, Blanice and Ostružná River basins

2 Characteristics of Water Basin Areas

The upper stream of the Ostružná River drains the high part of the Šumava Mountains (the Kocháňské plains). Most of the basins belong to the Šumava foothills. The highest place is situated at 1,177 m; the lowest part at 528 m in the Kolinec gauging site. The water basin covers an area of 92.42 km^2. 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%, at present. The countryside settlement is typical for this area (See Table 1).

The Vydra River drains the high part of the Šumava (Kvildské plains). The highest place of the basin is situated at 1,373 m and the lowest at 935 m in the Modrava gauging site. The water basin covers an area of 93.41 km^2. Metamorphic

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

DBNr	Gauging site	River	Monitoring from	A (km^2)	P^a (mm)	Q_a (m^3.s^{-1})	q_a (l.s^{-1}.km^2)	φ^a
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

DBNr database number, *A* area, *P* precipitation, *Qa* discharge, q_a specific outflow, φ runoff coefficient

[a]Data from 1961–2002, other from the beginning of measurement

Pre-Cambrian rocks with biotic granites prevail in the subsoil. Cryptopodsol and podsol are characteristic of the area; 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 Plains). The highest place is situated at 1,228 m and the lowest at 743 m in the Blanický Mlýn gauging site. The water basin covers an area of 85.21 km^2. 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 in the area.

3 Methods and Data Sources

The methodology of the research comprises analytical and synthetic procedures. The basic analytical procedure can be regarded as the analysis of the rainfall and runoff trend regime supplemented by an analysis of air temperature and snow parameter relationships. The method of simple-mass and double-mass curves was used as the first step for the evaluation of the trend in outflow values 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. In addition, double-mass curve analysis using measured and computed runoff by Searcy and Hardison (1960) was applied. The analysis itself was preceded by the necessary step of homogenizing the precipitation data, during which missing data were completed based on the results of a regression analysis of the time sequences of monthly precipitation from adjacent stations. For estimation of precipitation in the selected water basin areas, more interpolation methods were used, including Thiesen polygons, kriging and methods that considered altitude. The calculated average values were compared with the database of the Czech Hydrometeorological Institute (CHMI). The best results were obtained by methods that considered the altitude of rainfall stations (Kavan 2004).

Standard statistical testing methods were also applied to detect the trends: the Wilcoxon non-parametric test and the Mann–Kendall non-parametric test (Mann 1945; Kendall 1975; Gan 1998; Lindström and Bergström 2004; Xiong and Guo 2004; Fu et al. 2004).

A frequency analysis of high water level events was carried out as the next step. The frequency was assessed based on the occurrence of 5-year and larger events respecting the separation of individual flood waves. The analysis of runoff trend was followed through by an analysis of changes in the runoff distribution during the year.

The development of runoff in the selected 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 a 5-year moving averages of monthly, annual, and seasonal values. The basic source of input outflow and climate values was the CHMI database.

Following the analysis of the trends in runoff, rainfall and air temperature regimes, an analysis of changes in landscape use, river network training, and land drainage was carried out. The results were related to the duration of the water-level monitoring in the water basins, (i.e. approximately over the last 50 years). Long-term changes in land use were assessed based on cadastre register in 1845, 1948, 1990, 2000 (Bičík et al. 2003), recent land cover changes on satellite image interpretation in 1987, 1996, 2002 (Hais 2003) and with the help of database CORINE Land cover (1992, 2000). In selected parts of catchments, we used aerial photographs from 1949, 1983, 1999 and 2005 (Hintnaus 2008).

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 mapping, were used.

4 Analysis of Rainfall-Runoff Regime Trends

4.1 Analysis Using Simple-Mass and Double-Mass Curves

The method of simple-mass curves was used for the identification of significant changes in the water runoff regime. The curves were constructed for cumulated average daily discharge values in relative form. Considerable changes were identified

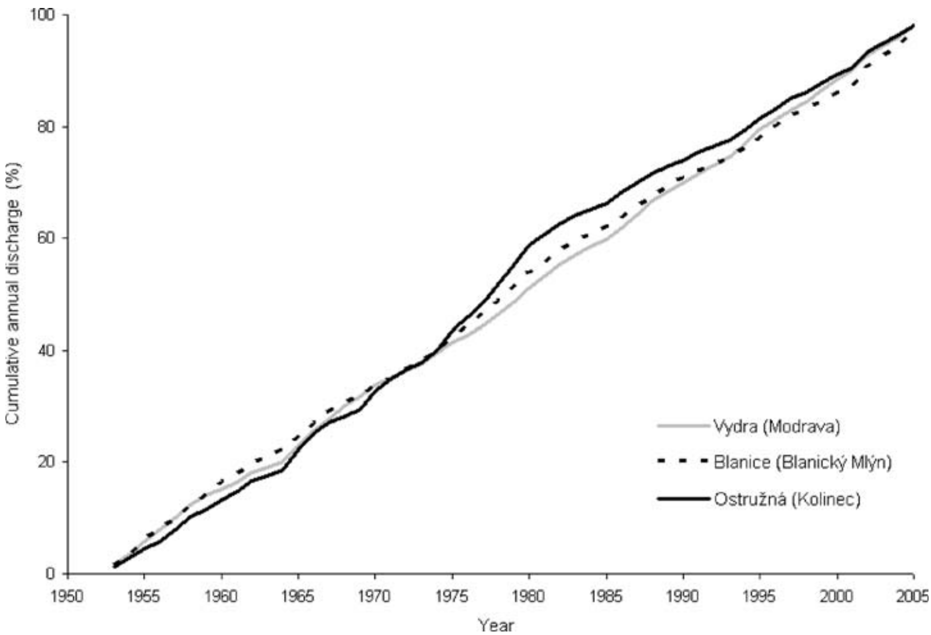

Fig. 2 Simple-mass curves of daily discharge values for the gauging sites: Modrava, Kolinec, and Blanický Mlýn (source: CHMI)

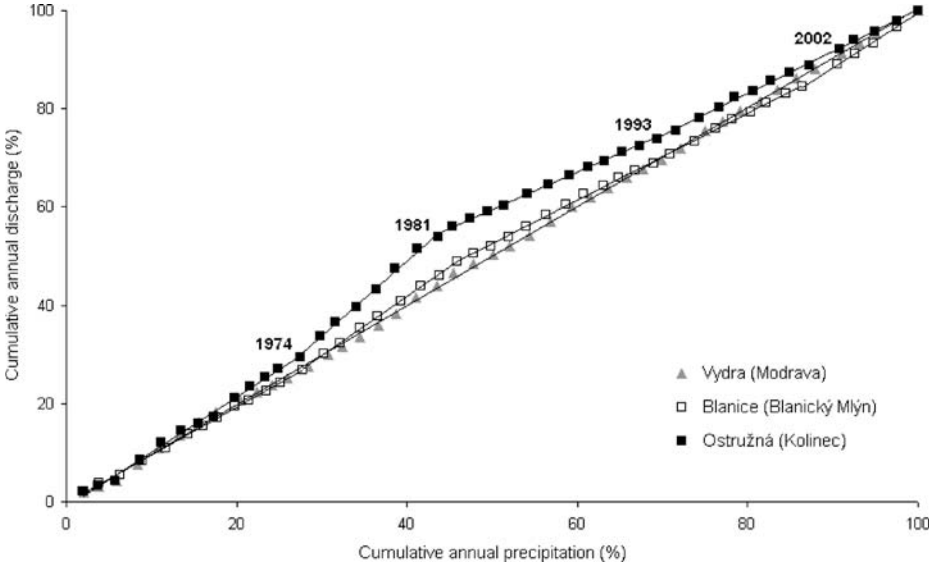

Fig. 3 Double-mass curves of annual precipitation and discharge for the gauging sites: Modrava, Kolinec and Blanický Mlýn

in the Ostružná River basin, where an increase in runoff was recorded in the period 1975–1982. 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 (See Fig. 2).

Another expression of rainfall-runoff relationship changes is an application of double-mass curve analysis. At first, double-mass curves were constructed using annual measured discharge and rainfall values. The results confirmed the findings

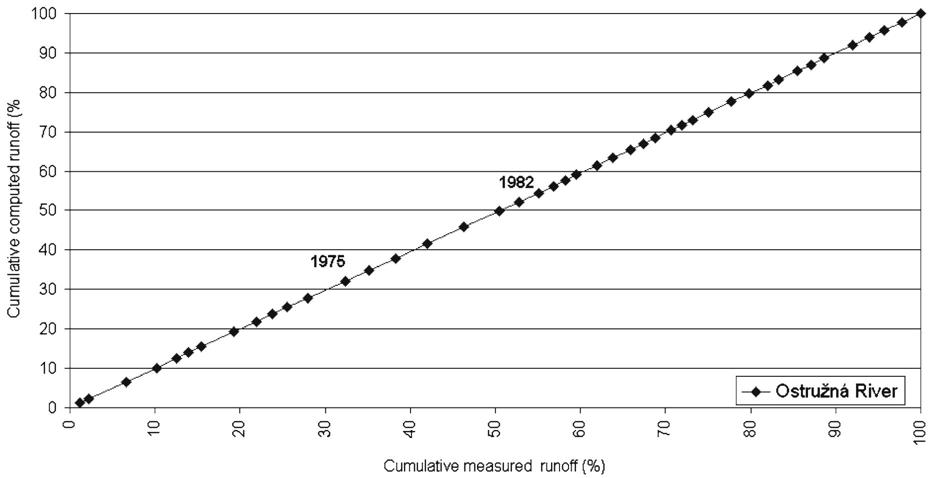

Fig. 4 Double-mass curve of computed and measured runoff for the gauging site Kolinec

of previous analyses of simple-mass curves (See Fig. 3). As a next step, cumulative measured runoff was plotted against cumulative computed runoff, taken from a precipitation-runoff relation (Searcy and Hardison 1960). Significant changes in the runoff-rainfall regime were not identified (See Fig. 4). The computed effective precipitation and computed runoff values showed lower correlation than measured precipitation and runoff values. We assume that the amount of precipitation that fell the previous hydrological year[1] did not affect so much the relation between precipitation and runoff in small low mountain and sub-mountain areas in temperate zone with metamorphic Pre-Cambrian rocks in the bedrock.

4.2 Trend Analysis Using Statistical Testing Methods

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-curve 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 the rejection of the null hypothesis, stating no difference between the sets, on this level. Statistically significant differences were both shown 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 (observation 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 x Ostružná Rivers [1975–1982: 1983–1990, $W_{0.05}(8) = 2$)], Ostružná x Blanice Rivers [1975–1982: 1983–90, $W_{0.05}(8) = 0$)]. The results confirmed the exceptional character of the development of discharges in the Ostružná River basin. In relation to further river basins under comparison and the periods evaluated, the decrease of discharge values for the period 1975–1982 was manifested statistically.

The Mann–Kendall non-parametric test (Mann 1945; Kendall 1975; Gan 1998; Libiseller and Grimvall 2002; Lindström and Bergström 2004; Fu et al. 2004) was used for studying the analogy of trends between the time series of average yearly discharges (*Qr*) and yearly precipitation (*Hr*). We also included testing on monthly discharges (*Qm*) and monthly precipitation (*Hm*). This test was selected because it can handle non-normality, censoring, or data reported as values "less than", missing values, or seasonality and because it has a high asymptotic efficiency (Berryman et al. 1988 in Gan 1998).

The analogy of trends between *Qr* and *Hr* was firstly tested based on the correlation matrix (Libiseller and Grimvall 2002) for the whole period 1962–2002. The dependence between *Qr* and *Hr* in the Vydra basins was identified (See Table 2).

[1]Hydrological year starts in studied areas at 1st of November and ends at 31st October; *Qm*, *Hm*, *Tm, Qr* and *Hr* values were calculated following the hydrological year.

Table 2 Correlation coefficient values based on Mann–Kendall test for *Qr and Hr* in the period 1962–2002

Period	Ostružná River	Vydra River	Blanice River
1962–2002	0.524	0.726	0.667
1962–1974	0.603	0.710	0.769
1975–1982	0.204	0.673	0.643
1983–1990	0.969	0.888	0.367
1983–2002	0.510	0.677	0.512

Qr average yearly discharge, *Hr* average yearly precipitation

Furthermore, selected segments of the time series of *Hr* and *Qr* were studied based on sudden trends analogy from previous analyses. In the case of the Vydra River basin, the correlation was found in all the three periods under observation (strong correlation in the periods 1962–1974 and 1983–1990). As for the Ostružná River basins, the dependence was identified in 1983–1990. In the period 1975–1982 when a substantial change occurred in the course of single-mass and double-mass curves, no correlation was identified. In the Blanice River basin, a low correlation between *Hr* and *Qr* was identified in the period 1983–1990.

The model river basins were further subjected to analysis using the so-called seasonal Mann–Kendall test (Dennis and Lonna 2006; Libiseller and Grimvall 2002; Gan 1998), based on the data series of *Qm*, *Hm* and*Tm*. The Mann–Kendall MK-S statistics for *Qm*, *Hm* and *Tm* were calculated for the period 1962–2002 (See in Table 3). Significant decreasing trend of Qm was identified in the Ostružná River basin in spring and summer. Decrease of Qm also occurred in April, May and June in the Blanice River basin. On the contrary, increase of Qm occurred there in February and March. No significant trends were identified in the data period studied of Hm, only moderate decrease of Hm in May and June in the Vydra River basin was observed, but this trend does not correspond with changes of Qm and Tm. Significant increase of temperatures in higher altitudes (stations: Kašperské hory and Churáňov) in March, May and August occurred.

The Mann–Kendall correlation coefficient values for the identification of trends analogy of *Qm* and *Hm* are presented in Table 4. The correlation of *Hm* and *Qm* was confirmed in all the periods observed in the Vydra River basin. On the contrary, it was not identified in Ostružná and Blanice River basins for the period 1975–1982.

4.3 Frequency Analysis of Higher Water Events

An analysis of the high water-level occurrence was carried out in order to explain the cause of significant changes in the runoff trend. The 5-year event level was used as the limit for high discharges. It was derived empirically using probability curves.

The analysis confirmed that the identified trend in the water runoff increase is connected with the occurrence of a high water level. In the period 1979–1981, a concentrated occurrence of higher water level events was recorded in all the observed the gauging sites. The occurrence of a high water level on the Vydra River did not manifest significant changes in the long-term runoff regime. Based on these facts, the

Table 3 The Mann–Kendall MK-S statistics for Qm, Hm and Tm, identification of trends in period 1962–2002

	Month	MK-S	*p*-value	Trend
Catchment				
Ostružná				
Qm	1	−0.921	0.357	–
	2	0.764	0.445	–
	3	−0.247	0.805	–
	4	0.236	0.814	–
	5	0.180	0.857	–
	6	−0.842	0.400	–
	7	−2.741	0.006	↓
	8	−3.370	0.001	↓
	9	−2.291	0.022	↓
	10	−2.447	0.014	↓
	11	−1.730	0.084	↓
	12	−0.786	0.432	–
Hm	1	0.292	0.770	–
	2	0.629	0.529	–
	3	1.056	0.291	–
	4	−1.280	0.200	–
	5	−1.550	0.121	–
	6	−0.629	0.529	–
	7	1.348	0.178	–
	8	0.494	0.621	–
	9	0.607	0.544	–
	10	1.640	0.101	–
	11	0.809	0.419	–
	12	1.438	0.151	–
Blanice				
Qm	1	0.988	0.323	–
	2	1.842	0.065	↑
	3	2.179	0.029	↑
	4	−1.707	0.088	↓
	5	−2.920	0.003	↓
	6	−2.673	0.008	↓
	7	−0.607	0.544	–
	8	−0.337	0.736	–
	9	−0.809	0.419	–
	10	0.292	0.770	–
	11	−0.280	0.780	–
	12	0.746	0.456	–
Hm	1	−0.090	0.928	–
	2	0.674	0.500	–
	3	0.247	0.805	–
	4	0.651	0.515	–
	5	1.303	0.193	–
	6	−0.921	0.357	–
	7	−1.280	0.200	–
	8	−1.730	0.084	↓
	9	0.876	0.381	–
	10	−0.876	0.381	–
	11	−0.303	0.762	–
	12	1.305	0.192	–

Table 3 (continued)

		Month	MK-S	*p*-value	Trend
Vydra					
	Qm	1	1.617	0.106	–
		2	1.123	0.261	–
		3	1.191	0.234	–
		4	2.808	0.005	↑
		5	1.078	0.281	–
		6	−0.494	0.621	–
		7	−2.291	0.022	↓
		8	−0.584	0.559	–
		9	−1.398	0.162	–
		10	0.753	0.452	–
		11	0.117	0.907	–
		12	0.047	0.963	–
	Hm	1	0.786	0.432	–
		2	1.011	0.312	–
		3	1.191	0.234	–
		4	−1.303	0.193	–
		5	−2.179	0.029	↓
		6	−1.797	0.072	↓
		7	0.854	0.393	–
		8	−0.382	0.703	–
		9	0.629	0.529	–
		10	−0.180	0.857	–
		11	1.393	0.164	–
		12	1.352	0.177	–
Station					
Klatovy					
	Tm	1	0.528	0.598	–
		2	0.910	0.363	–
		3	1.269	0.204	–
		4	1.539	0.124	–
		5	0.977	0.328	–
		6	2.584	0.010	↑
		7	−0.146	0.884	–
		8	1.045	0.296	–
		9	3.909	0.000	↑
		10	1.224	0.221	–
		11	0.371	0.711	–
		12	0.012	0.991	–
Kašperské Hory					
	Tm	1	1.842	0.065	↑
		2	1.572	0.116	–
		3	2.336	0.019	↑
		4	0.966	0.334	–
		5	3.572	0.000	↑
		6	0.899	0.369	–
		7	1.213	0.225	–
		8	3.370	0.001	↑
		9	−0.135	0.893	–
		10	1.146	0.252	–
		11	−0.494	0.621	–
		12	1.404	0.160	–

Table 3 (continued)

	Month	MK-S	*p*-value	Trend
Churáňov				
Tm	1	1.640	0.101	–
	2	1.617	0.106	–
	3	1.730	0.084	↑
	4	0.786	0.432	–
	5	3.527	0.000	↑
	6	0.764	0.445	–
	7	0.831	0.406	–
	8	3.639	0.000	↑
	9	−0.236	0.814	–
	10	0.213	0.831	–
	11	0.056	0.955	–
	12	1.393	0.164	–

– no trend, ↑ increasing trend, ↓ decreasing trend

occurrence of flood discharge is not a determining factor in the changes in the water runoff development.

4.4 Changes in the Seasonal Runoff Distribution

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. A gradual decrease was seen in the runoff in summer months during the last 20 years, with the exception of floods in August 2002. A considerable increase of the runoff (of more than 5%) was observed in the winter months, particularly after 1975. 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 (See Fig. 5).

5 Analysis of Air Temperature and Snow Parameters

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 its foothills: Churáňov, Kašperské hory and Klatovy (See Table 5). 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

Table 4 Correlation coefficient values based on Mann–Kendall test for *Qm and Hm*

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

Qm average monthly discharge, *Hm* average monthly precipitation

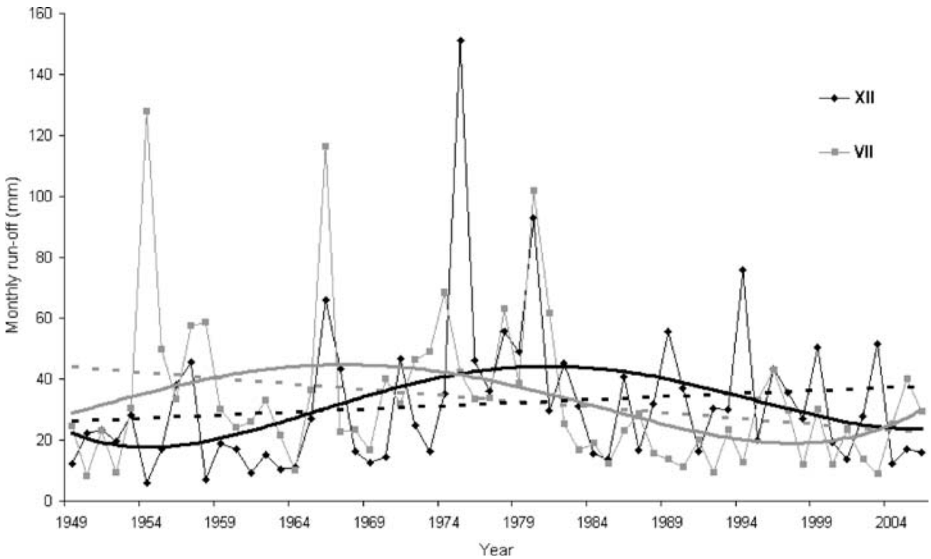

Fig. 5 Trends of run-off regime in December and July for the gauging site Kolinec. Linear and polynomic trends were used

the periods 1901–1950 (Vesecký et al. 1961) and 1951–2003, a rise in air temperature from 7.6°C (1901–1950) to 8.1°C (1951–2003) 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, were 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 Fig. 6. Similar trends were observed for all three stations.

The average number of days with snow covers was about 50 for the period 1950/1951–2003/2004, and is practically the same as the average value for the period 1920/1921–1949/1950. A certain reduction in the number of days of snow cover can be seen from the 1970s and, more significantly, during the 1990s (See Fig. 7). At the same time, despite the apparent increase in winter precipitation, the average snow cover depth was reduced by almost a half for the comparable amounts of winter precipitation.

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

Table 5 Mean annual air temperature and snow cover characteristic

Climatic stations	Klatovy	Kašp. Hory	Churáňov
Altitude (m)	430	737	1,118
Mean air temperature (°C)	8.1	6.2	4.4
Mean precipitation (mm)	607	830	1,098
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

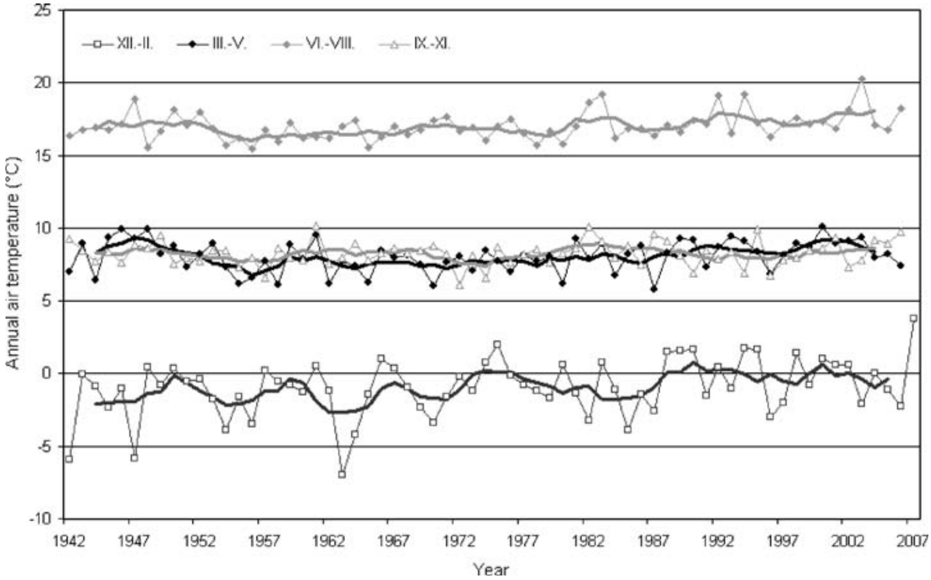

Fig. 6 Development of mean air temperature in the season periods, station Klatovy. 5-year moving averages were used (source: CHMI)

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.

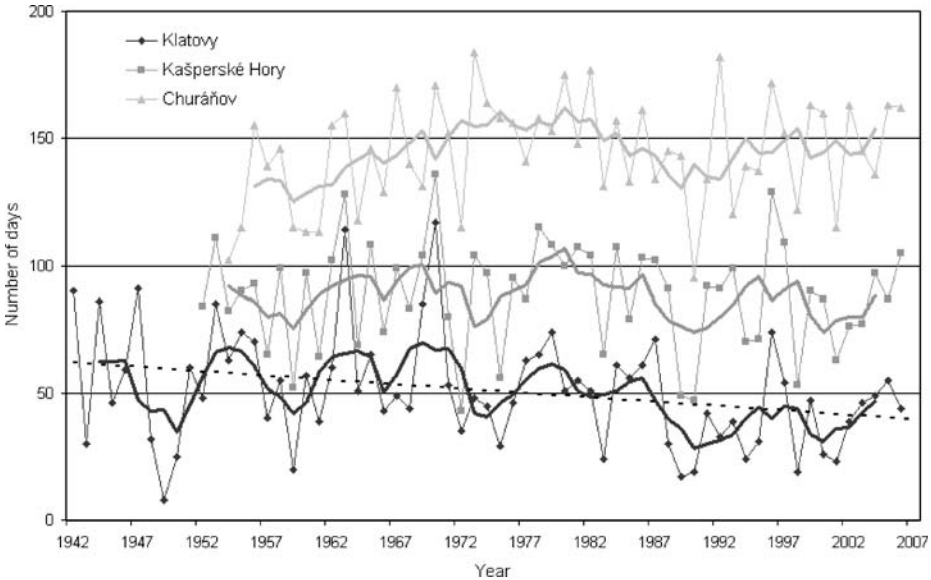

Fig. 7 Number of snow cover days in the winter period (XI–IV) for climatic stations Klatovy, Kašperské hory and Churáňov (source: CHMI)

6 Analysis of Land Use and Land-Cover Changes

The landscape changes reflect changes in political and economic conditions. According to Bičík et al. (2003), who compared the structure of land use on statistical data from cadastre unit records 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 the forest. The same result confirmed the interpretation of aerial images in sources areas of the Blanice River (Hintnaus 2008—see Fig. 8, Table 6) and the satellite image analysis of the Otava River basin (Hais 2003). 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. The introduction of large-area farming led to the loss of the stabilizing elements in the landscape. Intensive agriculture was accompanied by extensive land drainage of swamped areas and the straightening of smaller rivers. As a result of state

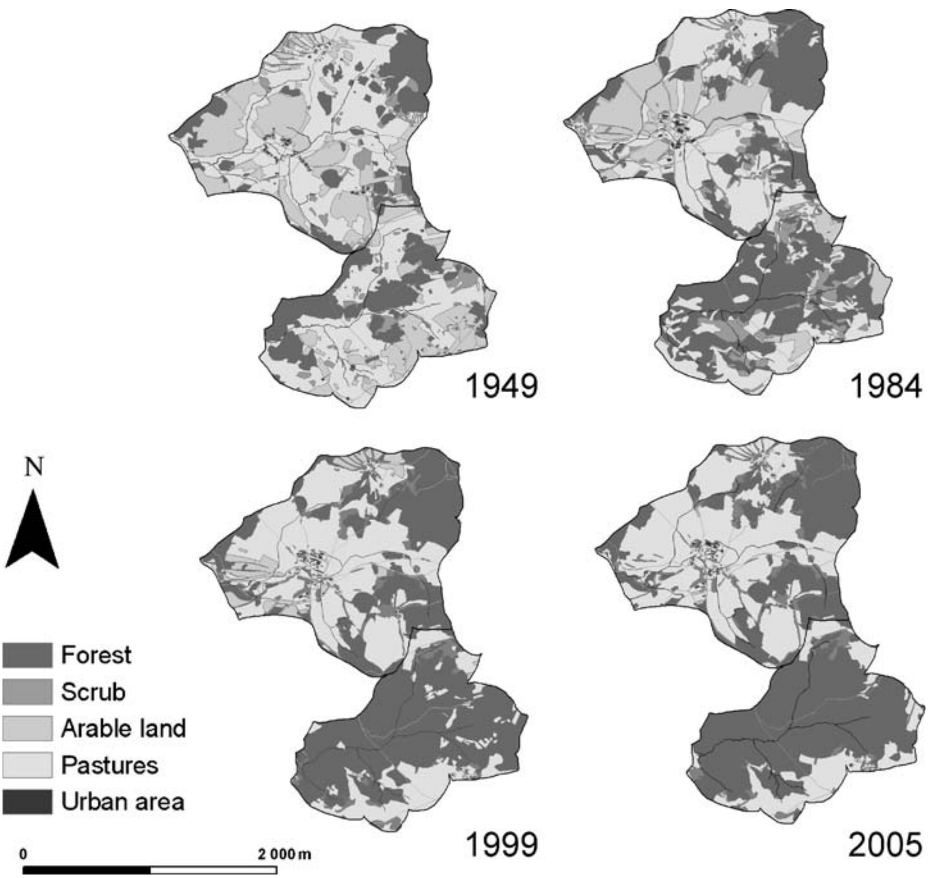

Fig. 8 Land cover changes in the Zbytinský Brook and Tetrívcí Brook basins – sources area of the Blanice River basin, (source: Hintnaus 2008)

Table 6 Land cover changes using aerial images of the sources areas of the Blanice River basin

Land cover class	1949		1984		1999		2005	
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
Arable land	412.6	24.7	252.0	15.1	65.7	3.9	1.1	0.1
Pastures	784.4	47.0	619.0	37.1	664.9	39.8	698.3	41.9
Forest	374.0	22.4	633.9	38.0	816.5	48.9	844.0	50.6
Scrub	75.3	4.5	138.2	8.3	94.9	5.7	97.1	5.8
Urban area	5.9	0.4	6.3	0.4	6.0	0.4	6.1	0.4
Other area	16.4	1.0	19.2	1.1	20.6	1.2	22.0	1.3
Total	1,668.6	100	1,668.6	100	1,668.6	100	1,668.6	100

subsidies, the Šumava foothill areas have been extensively grassed over after 1994 (See Table 7).

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 (see Fig. 9). Similar changes together with forestation have also occurred in the Blanice River basin.

7 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 the river network in the nineteenth century did not represent significant interventions into the river

Table 7 Land cover changes of the studied 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

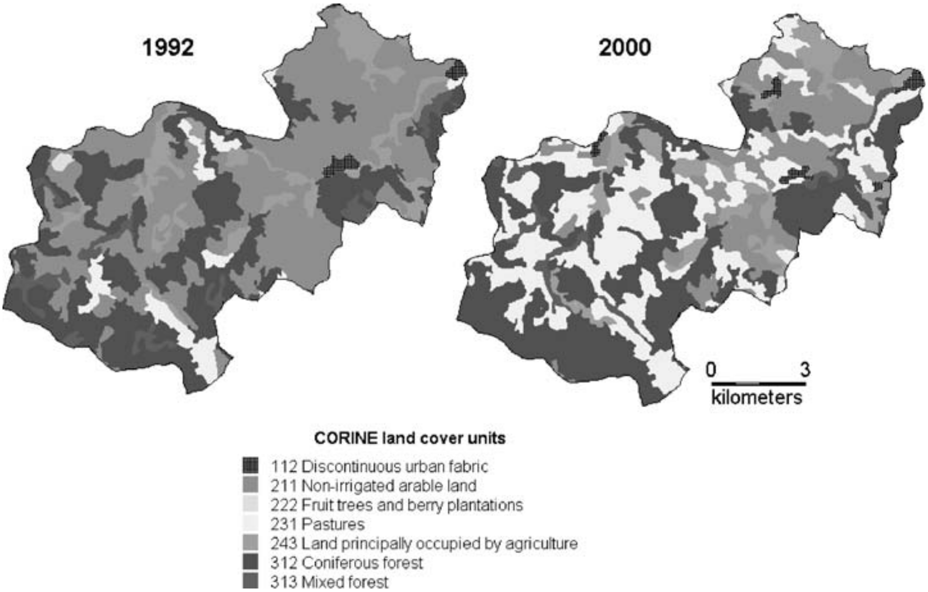

Fig. 9 Land cover changes in the Ostružná River basin (source: CORINE Land cover)

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 (See Table 8).

The Blanice River basin has a significantly lower level of channelized sections mainly in the Zbytinský Brook basin. The level of river altering totals only 6% in the whole Blanice River basin but in the Zbytinský Brook basin, reaches 62% (Vondra 2004). No significant anthropogenic interventions to the river network were identified in the Vydra River basin except for forest amelioration in the nineteenth and twentieth centuries (Hais 2004).

Land drainage was 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

Table 8 River altering in the Ostružná and the Blanice River basins

	Ostružná	Blanice
River network length (km)	163.9	141.9
River modification length (km)	33.7	8.5 (18.4[a])
Transformation degree (%)	20.6	6 (13.0[a])

[a] Including historical modification, which are now in near natural state

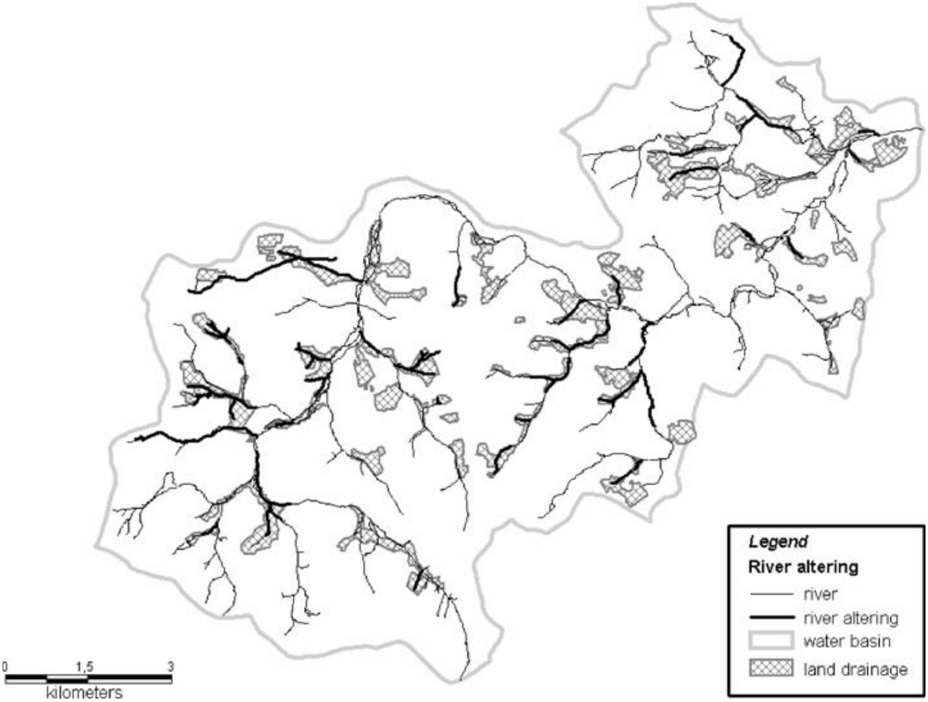

Fig. 10 River training and land drainage in the Ostružná River basin (source: AWMA Prachatice)

drainage reached 829 ha in the Ostružná River basin (i.e. 8.3% of the river basin area, see Fig. 10). In the case of the Blanice amelioration, measures were applied from the beginning of the 1970s. The largest draining period corresponded with the situation in the Ostružná River basin. The total amount of land drainage reached 450 ha (i.e. 5.3% of the river basin area, see Fig. 11).

8 Discussion

Different methods were applied to detect runoff trend. Results from simple-mass and double-mass curve analyses were validated using statistical tests. Wilcoxon and Mann–Kendall tests confirmed the supposed changes from the simple-mass and double-mass curve analysis using measured values in the runoff development.

An analysis of discharge characteristics showed a continuous period of higher runoff during the period 1975–1982 during both the growing and cold seasons. There were several incidences of shorter periods of high water-level events; usually lasting 2 to 3 years, during the 50-year sequence monitored, for example, 1957–1958, 1965–1966(67), 1970–1971, 1995–1997 and 2002. After 1982, lower or low water runoff values were seen, particularly during the growing periods (See Fig. 12).

The period of higher runoff between 1975 and 1982 is connected with a period of higher precipitation. However, compared to similar situations (1954–1958, 1965–1968, 1986–1988, 1995–1996, 2000–2002, etc.), the given period can be described as

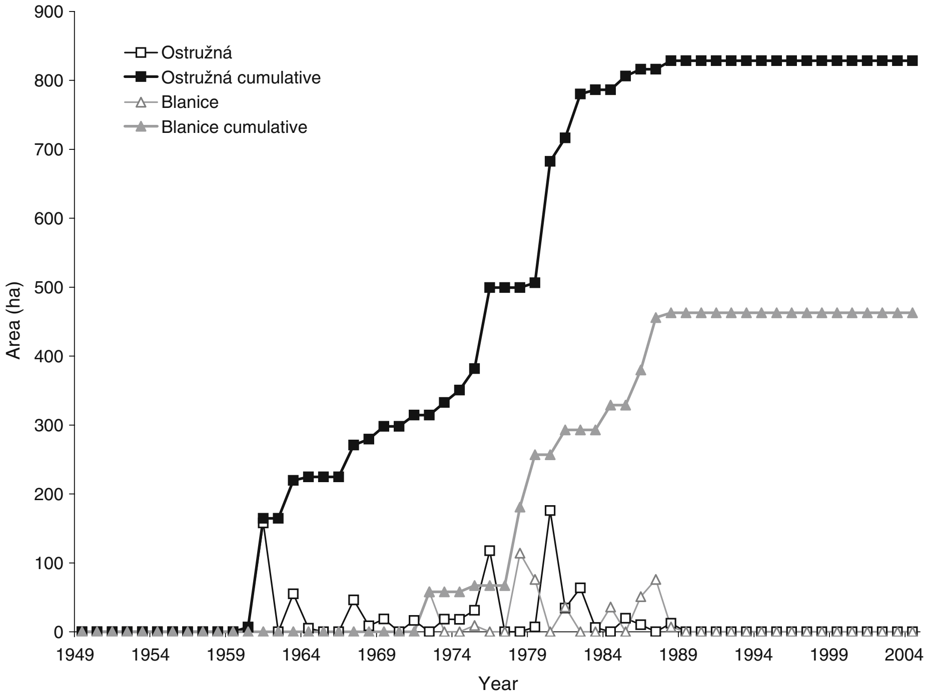

Fig. 11 Land drainage in the Ostružná and Blanice River basins (source: AWMA Prachatice)

not completely adequate from the point of discharge values in relation to the amount of precipitation. From the point of precipitation, it is a continuous period of average to above-average years without considerable deviations. If we monitor trends in the whole 50-year sequence, wetter and drier periods alternate. From the end of the 1970s, there was a clear decrease and higher fluctuation of precipitation in the vegetation period and a 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 during the winter period. Looking at the 50-year sequence as a whole, there was air temperature increase considerably from the beginning of the 1980s and more so during the 1990s, during both the summer and winter months.

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

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

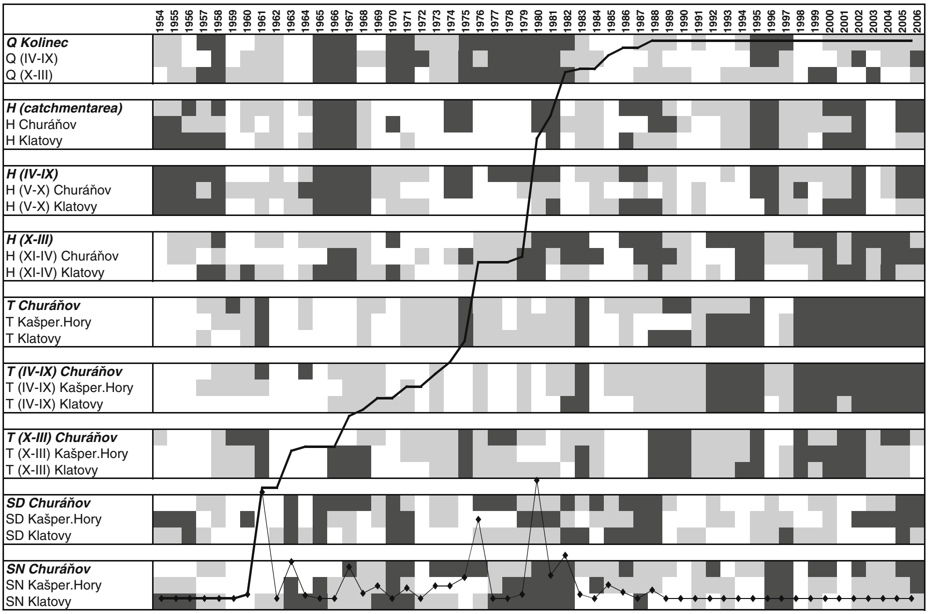

Fig. 12 Climate development and increase of land drainage in the Ostružná River basin in the period 1954–2006 (source: CHMI, AWMA). *Q* mean discharge, *H* precipitation, *T* mean air temperature, *SD* snow cover depth, *SN* number of days with snow cover. *Black color areas* values >upper quartile; *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)

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

Extensive amelioration measures were carried out in the Ostružná and Blanice River basins in the second half of the twentieth century. Large areas used for agriculture were drained, and in connection with this, small river channels were altered. The greatest increase in drained areas occurred between 1975 and 1982, which corresponded with the identified increase in runoff in this period.

9 Conclusion

Through the assessment of the runoff and rainfall processes using the method of simple-mass and double-mass curves and statistical tests, deviations in the trend of runoff were observed. Out of the three studied water basins in the Šumava Mountains and its foothills, the largest deviations were seen in the Ostružná River basin, which is mainly 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 number of days of snow covers. After 1982 and particularly in the 1990s, lower-than-average and low runoff values were 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 training and the construction of subsurface drainage systems. The period with the most intensive increase in drained areas corresponded with the increase in water runoff.

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