Changes in runoff regimes in small catchments in Central Europe: Are there any?

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Abstract The objective of this paper is to explore what measured data in selected small, relatively undisturbed European catchments tell us about the frequency of floods over the past four decades. Daily discharge data from three mountain catchments in Germany, the Czech Republic and Slovakia from 1962 to 2001 was analysed. The analysis focused on trends in mean annual runoff, the seasonal distribution of runoff, maximum annual runoff, and the occurrence of high and low flows. The study did not confirm the hypothesis that the frequency of high flows is increasing. Distinct changes were only related to the seasonality of maximum annual runoff and the number of runoff events and dry periods in summer months.

Key words frequency of floods; trends in runoff regime; small catchments

INTRODUCTION

Severe floods that occurred recently in Africa, North America and Europe have brought much attention to this traditional hydrological issue and it is sometimes claimed that the frequency of floods is increasing. The primary objective of this paper was to test this hypothesis in small, relatively undisturbed European catchments.

The definition of a flood can be ambiguous. A researcher studying runoff generation could denote every runoff event as a flood. For a statistician, a flood could be represented by all peak discharges exceeding certain a threshold. Public understanding of floods is associated with high flows accompanied by property damage or even casualties. In addition to the ambiguity of their definition, hydrological extremes exhibit spatial variability as well.

Although it is commonly stated that the frequency of floods is increasing, an overview of written evidences about big floods in central Europe since the 11th century does not indicate their frequency is increasing. For example, Adamčák & Filip (1999) report that while the last large floods on the Danube occurred in 2002, there were major floods in 1012, 1210, 1501, 1526, 1572, 1594, 1598, 1670, 1682, 1721, 1787, 1809, 1876, 1897, 1899, 1954, 1965. Brázdil et al. (2005) presented historical data on floods in the Czech Republic from the period 1351–2000. They concluded that the highest number of floods occurred in the 19th and in the second part of the 16th centuries. The flood frequency in the 20th century was comparable with that of the 17th century. Floods in Germany were summarized by Glaser (2001) and Sturm et al. (2001). Although the variability of flood frequency was not always identical with that found in the Czech Republic, they also found a maximum in the 16th century.

Historical data from annals and other sources (water marks, personal correspondence, paintings, etc.) represent invaluable information that extends our climatological/hydrological records and enables study of the natural variability of extreme events over long time intervals. However, when testing the hypothesis on increased flood activity in the recent period, there is more precise measured runoff data available. It could be expected that if the frequency of high flows is increasing, it should be easily detected in measured data. The aim of this paper is to determine what measured data from small mountainous catchments indicate about the changes in the runoff regime in the last four decades.

METHOD AND DATA

Analyses of time series of hydrological data were performed on data collected since the middle of the 20th century. They resulted in a number of studies which can be roughly divided into three
groups (Pekárová, 2003) focused on:
- natural variability and periodicity of meteorological and hydrological data
- detection of the long-term trends in time series
- teleconnections of time series with general circulation of atmosphere and hydrosphere

The time series analyses are often done with annual or monthly data using sophisticated statistical methods. Here we have analysed series of daily runoff for the hydrological years 1962–2001 from three small mountain catchments in Central Europe using simpler techniques. These watersheds are located in Germany, the Czech Republic and Slovakia and occur along a gradient of increasing continental influence. The objective is the analysis and discussion of real data series, instead of exhaustive statistics, and focuses on changes in: annual runoff, the seasonal distribution of runoff, maximum annual runoff ($R_{\text{max}}$) and its seasonal occurrence, the number of runoff events, and the frequencies of high flows and droughts. The statistics of runoff events was based on the events that approximately reached or exceeded the mean daily runoff in a particular catchment. High flows events were defined as flows that occurred on 10% of the days ($R_{10}$). Droughts were defined by a fixed threshold representing flows which occur or are exceeded on 90% of days ($R_{90}$).

According to the classification of Pardé (1933) the hydrological regime of all three catchments (Fig. 1, Table 1) can be characterized as mixed snowmelt–rainfall. The Lange Bramke catchment of the Harz Mountains in Germany, has an oceanic climate. It is made up by Lower Devonian rocks (quartzites, fine-grained quartzitic sandstones, sandy-silty slates) covered with autochthonous weathering and Pleistocene solifluvial materials. Hydrological research in the catchment started in 1949.

The Bílý potok catchment of the Jizera Mountains is situated in the wettest part of the Czech Republic. It is underlain by Proterozoic granitic rocks (granite-granodiorite). The bedrock is covered with shallow Quaternary deposits. Runoff measurements in the catchment started in 1956.

The Bystrianka catchment of the Low Tatra Mountains in Slovakia, has a climate that represents a transition between oceanic and continental climates. The upper part of the catchment is underlain by gneiss. The lower part of the catchment is underlain by more variable Triassic rocks (limestone, sandstone, greywacke). Shallow Quaternary deposits overlay bedrock throughout the basin. Runoff measurements in the catchment started in 1923.

![Fig. 1 Location of the study catchments; 1-Lange Bramke, 2-Bílý potok, 3-Bystrianka.](image-url)
Table 1 Basic characteristics of studied catchments, where E, P, R and T are elevation, mean annual precipitation, runoff and air temperature, respectively.

<table>
<thead>
<tr>
<th>River basin</th>
<th>Area (km²)</th>
<th>Forested area (%)</th>
<th>E (min–max, mean) (m a.s.l.)</th>
<th>P (mm)</th>
<th>R (mm)</th>
<th>T (ºC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lange Bramke</td>
<td>Weser</td>
<td>0.8</td>
<td>90</td>
<td>543–700, 661</td>
<td>1300</td>
<td>700</td>
</tr>
<tr>
<td>Bílý potok</td>
<td>Oder</td>
<td>26.1</td>
<td>80*</td>
<td>505–1124, 880</td>
<td>1517</td>
<td>1183</td>
</tr>
<tr>
<td>Bystrianka</td>
<td>Danube</td>
<td>34.4</td>
<td>70</td>
<td>650–2024, 1184</td>
<td>1370</td>
<td>890</td>
</tr>
</tbody>
</table>


RESULTS

Long-term runoff and its seasonality

The mean annual runoff in hydrological years 1962–2001 in the Lange Bramke, Bílý potok and Bystrianka catchments was 622 mm, 1145 mm and 836 mm, respectively. All data series exhibit a wetter period in the second half of the 1960s and a relatively dry period in the second half of the 1980s (Fig. 2). Data from Lange Bramke and Bystrianka show a slight decreasing trend caused by the difference between higher runoff in the 1960–1970s and lower runoff in the 1980–1990s. No trend is visible in the Bílý potok catchment where the second half of the 1990s was wetter.

The transition from the oceanic to continental climate of the catchments is reflected in the seasonal distribution of runoff (Fig. 2). Although the seasonal distribution of runoff varies in particular years, a year-by-year analysis does not indicate any distinct trend or changes. The differences in seasonal distribution of runoff among the catchments were the smallest in the year of 1970 when all the catchments had low runoff in November–March and a pronounced maximum in April or May.

High flows, number of runoff events, low flows

The analysis of the frequency of high flows was the main objective of this study. The time series of maximum daily runoff (Rmax) do not indicate an increasing trend (Fig. 3). On the contrary, more recent values were smaller than the values observed in previous decades. The analysis of the frequency of higher values of Rmax in the past decade does not indicate a dramatic increase compared to previous decades. Only in the Lange Bramke catchment it can be concluded that a higher Rmax occurred in 5 of 8 years since 1994 (Fig. 3). Although Rmax was higher in previous decades, such a frequency was not observed in the catchment before 1994.

Rmax in the Lange Bramke catchment typically occurs in winter and spring (Fig. 3). Unlike in previous decades, Rmax has only once occurred in October–December since 1992. In Bílý potok, Rmax typically occurs in April, July and August. In Bystrianka, Rmax usually occurs in April and May.

![Fig. 2 Annual runoff in hydrological years 1962–2001(bar charts) and mean monthly runoff (line chart).](image-url)
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Fig. 3 Maximum daily runoff $R_{\text{max}}$ (line chart) in the studied catchments (1-Lange Bramke, 2-Bílý potok, 3-Bystrianka) in hydrological years 1962–2001; maxima in the Bílý potok catchment in hydrological years 1964, 1977 and 1981 reached 109.8 mm day$^{-1}$, 167 mm day$^{-1}$ and 170.6 mm day$^{-1}$, respectively. The bar charts show the month of occurrence of $R_{\text{max}}$ from January (1) to December (12).

Fig. 4 Time series of high and low flows; $R_{10}$ is the threshold that represents the highest 10% and $R_{90}$ the lowest 10% of measured daily runoff, respectively.
Further analysis was devoted to the highest 10% of the daily flows ($R_{10}$). These flows are equal to runoff that is equal or higher than 3.87, 6.32 and 5.04 mm day$^{-1}$ in Lange Bramke, Bílý potok and Bystrianka, respectively. The highest occurrence of $R_{10}$ in the Lange Bramke catchment was observed at the beginning of 1980s (Fig. 4). Bílý potok is the only catchment in which the occurrence of $R_{10}$ seems to increase since 1992, although the maxima are lower than in earlier decades (Fig. 4). $R_{10}$ in the Bystrianka catchment decreased in the 1990s.

The final analysis focused on the number of runoff events and droughts in particular years (Figs 4 and 5). The frequency of dry periods increased recently in only the Lange Bramke catchment. In the other two catchments, it decreased. The number of runoff events, i.e. the events with the peak flows reaching or exceeding the mean runoff, in the Lange Bramke and Bystrianka catchments in 1992–2001 decreased slightly (Fig. 5). Analysis of seasonality has shown that since the 1980s the runoff events in the Lange Bramke catchment in May to August almost disappeared. The reduction in the number of events in August in the last years was also found in the Bystrianka catchment.

DISCUSSION
The main objective of our analysis was to evaluate the hypothesis that high flows in small undisturbed catchments occur more frequently in the present than in the recent past. This hypothesis was not confirmed in these three, undisturbed study basins. This suggests that the increase in damage caused by floods that was reported in the past few years was not caused by increased high flows in small undisturbed catchments and thus has other causes.

We realize that big floods are often connected with large river basins. Nevertheless, we believe that data from small catchments can be good indicators of changes and causes in the frequency of floods. There are several reasons for such an argument. The network of properly selected small catchments has been successfully, and repeatedly used to represent the regime of large river basins (Balek, 2006). Small catchments often have more consistent data than large river basins and the devastating floods often originate in small catchments (e.g. Balek, 2006).

CONCLUSIONS
The analysis of measured runoff data from three small, relatively undisturbed Central European catchments did not indicate an increasing frequency of high flows. On the contrary, the maxima
measured in the last two decades do not reach the values that occurred in the previous two decades.

The only obvious changes in daily runoff seem to be observed in the Lange Bramke catchment. This catchment has an oceanic climate and maximum annual runoff in the catchment in the last decade rarely occurred in October–December. At the same time, the number of runoff events in May to August was substantially reduced and dry periods have been rather frequent since the mid-1990s. A reduction of the number of events in August was also found in the Bystrianka catchment.

Statements on increasing frequency of floods should be supported by the analysis of measured data. Regionalization of high flow data from small catchments provided by international networks has the potential to address this issue and highlight the regions with changing hazards. This potential has not been fully used until now.

REFERENCES