

PEATBOGS HYDROLOGICAL FUNCTION: CASE STUDY OF UPPER OTAVA RIVER BASIN

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Abstract

In context of catastrophic floods and extreme droughts in recent years there is an urgent need of solving of flood protection and drought problem questions using also untraditional practices such as gradual increase of headstream areas retention capacity. Therefore thorough analysis of peatbogs hydrological function and qualified reference of former ameliorative channels dyking implemented in Otava River headwaters (southwestern Czechia) is carried out by detailed comparison of hydrological regimes in its subcatchments with different peatland proportion. This territory represents the core zone of a number of extreme flood events in Central Europe in recent years (Flood 2002). Peatbog influence on hydrological process can be considered also with respect to its affecting of water quality, respectively to ionic content including carbon and oxygen isotopes balance of water in periods of high or low discharges.

This project currently bear on existence of several water measure profiles with long time data series, on using modern methods (automatic ultrasound and pressure water level gauges, shuttle precipitation gauges) and upon results of bog pools detailed research. Thorough analyses of extreme runoff phases show higher frequency of peak flows and their shorter reaction to causal rainfall in case of highly peaty areas, therefore more distinct runoff variability of streams draining peatland localities.

The problem of peatbogs hydrological function depends on a number of factors considering its type, health state, rate of anthropogenic impact, etc. In addition to considering dyking of former drainage channels we should also evaluate possible former accumulation reservoirs (used for wood floating) restoration with potential function as dry polders. Using complex system of hydrological models we can simulate runoff process and assess the effectiveness of these reservoirs. Implementation of such unforceable measures could contribute to reduction of peak flows and to increase of water resources during extreme droughts in future.

Keywords: *peatbogs hydrological function - headstream area - flood protection - retention capacity - water level gauge - runoff variability - peak flow - drought.*

1 INTRODUCTION

Specific part of wide complex of flood protection measures and one of possible ways of prevention against floods and extreme droughts could be procedures realized in river headstream areas.

In order to enhance the retention potential in headwaters the detailed analysis of peatbogs hydrological function needs to be done. The peatland influence on runoff conditions and other hydrographic and climatic characteristics is being assessed by detailed comparison of hydrological regimes in two subcatchments with very different peatland proportion. The research is concentrated to Otava River Catchment (Vltava River source area, southwestern Czechia) representing a basin with frequent occurrence of flood events and with a high heterogeneity in terms of physical-geographic and social-economic aspects. We can reason about the peatbogs influence on hydrological process also with respect to its affecting of water quality, respectively to ionic structure of water in periods of high or low discharges (Novák, 1955; 1959; Onderíková, Štěrbová, 1956; Oulehle, Janský, 2003).

The problem of peatbogs hydrological function has not been so far fully solved despite a number of domestic and foreign projects and broad debates among experts. Opinions on such issues vary as it is evident in the literature that has been dealing with these questions already in the second half of the 19th century. The detailed analysis of various approaches was made by Ferda (1960). The so called "theory of sponge", which was in a literature acknowledged approximately from the last 60s, supposed the importance of peat land for its significant water retention and discharge regulating capability during high rainfall totals and its discharge heightening and runoff balancing in dry periods. From the last 70s studies that infirm the peat bogs retention function appear. They assert that only possible way to increase their retention capacity is to lower groundwater level by means of a drainage. Then these ameliorative hits were realized in a number of mountainous areas in Czechia. Since that time, the problem of drainage, respectively dyking of former drainage channels, has become the field for broad debates within the literature (Conway, Millar, 1960; Burke, 1967; McDonald, 1973; Moklyak et al., 1975; Baird, 1997; Holden et al., 2001; etc.). The detailed study of literature representing both opinion poles was carried out by Holden et al. (2004).

Results of studies dealing with this research subject proved that water courses draining peatland areas show significant discharge variability and that the peatland influence on runoff regime balance had been overestimated in past. It was found out that winter snow precipitations have a relatively low influence on discharge increase in summer period while summer rainstorms play a very significant role in this sense. While filling peat bogs up, runoff values increase rapidly. As well, during longer droughts, peatland does not play any positive role in hydrological terms, i.e. they do not feed water courses draining them. On the contrary, the past research projects state the hydrological regime improvement after peatbogs drainage and ameliorating. Peatland influence on water quality in water courses is assessed as unambiguously negative while intensity of affection is related to its area and volume in a catchment. The problem of pollution is further intensified in water reservoirs located in former peatland and moor areas.

Mentioned topic is currently studied in upper Otava River Catchment (Janský, Kocum, 2007a, 2007b and Kocum, Janský, 2007a, 2007b). Outcomes of the research is considered to be used within the realization of specific effective flood protection measures in cooperation with all concerned institutions (including flood warning system, etc.). Assessment of peat bogs revitalizing measures influence of chosen localities on its hydrological regime change is also one of the project goals. Every single element of rainfall-runoff process, especially snow conditions in the study area, needs to be completely studied. In order to increase retention potential in this area a qualified reference of measures being implemented at present in several localities in connection with former ameliorative channels (made during communist regime) dyking needs to be done.

The influence of peatbog localities on runoff process is assessed by detailed comparison of Vydra River and Křemelná River runoff regimes (Otava River main sources with very different peatland proportion in their catchments). Profile Otava River - Rejštejn (1-1-08-01-040-01, catchment area 336,5 km² (Water Research Institute (WRI) GIS layers), long-term mean discharge $Q_a=7,56$ m³/s (Czech Hydrometeorological Institute (CHMI) data) is the closing profile of the study area.

2 METHODOLOGY

More than 30 years ago the first results related to peatbogs hydrological function were presented within the study of CHMI in Prague (Ferda, Hladný, Bubeníčková, Pešek, 1971). In this project drainage and ameliorating of peatbog beds is recommended with regard to an improvement of their hydrological function. According to results from domestic and foreign literature it is stated that maximum discharges could be markedly reduced this way as a result of groundwater level decrease and consequently of extension the depth of peatbog surface layer for capturing causal rainfall totals. It is hereat adverted to other positive effects such as increase of forest stand accretion on drained areas (Vidal, Schuch, 1963; Huikari, 1963; Robertson, Nichol森, Hughes, 1963). This study is so far the last paper dealing with hydrological regime and water chemism in upper Otava River Catchment focused on peatbog habitation.

In recent years Otava River headstream area has become the study catchment of the research consisting partly in bathymetric mapping of organogenous lakes (bog pools, so called Bohemian Forest Moors) including specification of their main physical parameters and chemical composition, but especially in the initiation of thorough monitoring of Vydra and Křemelná River runoff regimes inclusive of assessment of various measures leading to their source areas retention potential increase. Very favourable conditions for realization of this project currently bear on a better accessibility to the study area and lengthening data time series but also on using quite modern equipment and methods.

At the end of 2005 six water level laths were installed in chosen profiles (Roklanský Brook, Modravský Brook, Filipohuťský Brook, Vchynicko-tetovský Floating Channel - Rechle, Křemelná River above Prášilský Brook, Prášilský Brook above Křemelná River) in order to initiate hydrological observations. Till recent years water level values had been read constantly by local observers in a one day step (during melting process in spring period twice a day) in these profiles. Since summer period 2006 seven automatic ultrasound and pressure water level gauges with dataloggers for continual monitoring of water level fluctuation (6 in Vydra River Catchment, 5 in Křemelná River Catchment; fig. 1 and 4) were subsequently installed beyond these profiles. Furthermore 4 limnigraphic stations within the CHMI limnigraphic stations network (Otava River - Rejštejn, Křemelná River - Stodůlky, Vydra River - Modrava, Hamerský Brook - Antigel) and two profiles controlled by CEZ energetic group (Vchynicko-tetovský Floating Channel - Rechle and Mechov) became parts of the research network system. Besides, two shuttle precipitation gauges measuring in 10 minutes step the amount of precipitation (fig. 1 and 4) were installed in the upper part of Vydra River Catchment (Rokytká Brook; measures since September 18, 2006 excepting two months in winter period) and Křemelná River Catchment (Zhůvecký Brook; measures since March 29, 2007). From technical reasons the amount of snowfall during winter period cannot be measured in mentioned profiles.

Measuring set from Fiedler-Mágr Company including registering and controlling unit of M4016 type, ultrasound or pressure sensor and GSM module for data transmission by means of GPRS network is used for continual water level monitoring in 10 minutes step and 1 mm accuracy. Data transmission in one day interval or shorter depending on the dynamics of hydrological situation allows its operative solution and also regular control of whole measuring set function. In given profiles with installed water level gauges periodical discharge measurements using

hydrometric propeller are carried out in order to construct an accurate consumption curves.

3 RESULTS

The main part of the project is the assessment of hydrological regime in the headstream area of Otava River Catchment including evaluation of various measures for its retention potential enhancement and comparison of runoff variability in chosen catchments with respect to the peatland proportion. In order to reach the goal the assessment and comparison of runoff variability partly in Vydra and Křemelná River Basins in the state profiles with relatively long time series partly in experimental catchments with very different peatland proportion is carried out.

3.1 Runoff regime analysis in Vydra and Křemelná River Catchments

In order to compare hydrological regimes in basins of Otava River two main sources, Vydra and Křemelná Rivers, from the runoff variability point of view, the data of mean daily discharges in limnigraphic stations within the CHMI basic network of water level gauges are used. Two of these profiles are discussed: Vydra River - Modrava (catchment area 90,17 km²; WRI GIS layers), long-term mean discharge 3,483 m³/s (CHMI data), peatland proportion 38% (Ferda, Hladný, Bubeníčková, Pešek, 1971)) and Křemelná River - Stodůlky (134,11 km², 3,722 m³/s, 5%) (Fig. 1). With respect to the fact that time series in studied profiles are not of the same length, the time period when both limnigraphic stations were in function is assessed. Accordingly the period 1.11.1999-31.10.2006 was analysed. This relatively short period could appear to be non-representative, yet basic statistical analyses of daily, monthly and annual time series were made and runoff was on the base of its variability graphically defined from the daily and monthly discharges point of view (Fig. 2) and described by characteristics presented in Tab. 1. On the basis of these outcomes it could be presumed that runoff variability appears to be slightly higher in the case of Vydra River - Modrava profile. This fact is demonstrated especially by K_r coefficient used for runoff assessment from the monthly discharge variability point of view. Higher runoff fluctuation is accordingly described in the profile closing the catchment with more significant peatland proportion. It is also evident by comparison of the ratios of maximum (April) and minimum (December) mean monthly discharge in studied profiles which reach up to 3,83 in the Vydra River - Modrava profile, respectively 3,35 in the Křemelná River - Stodůlky profile.

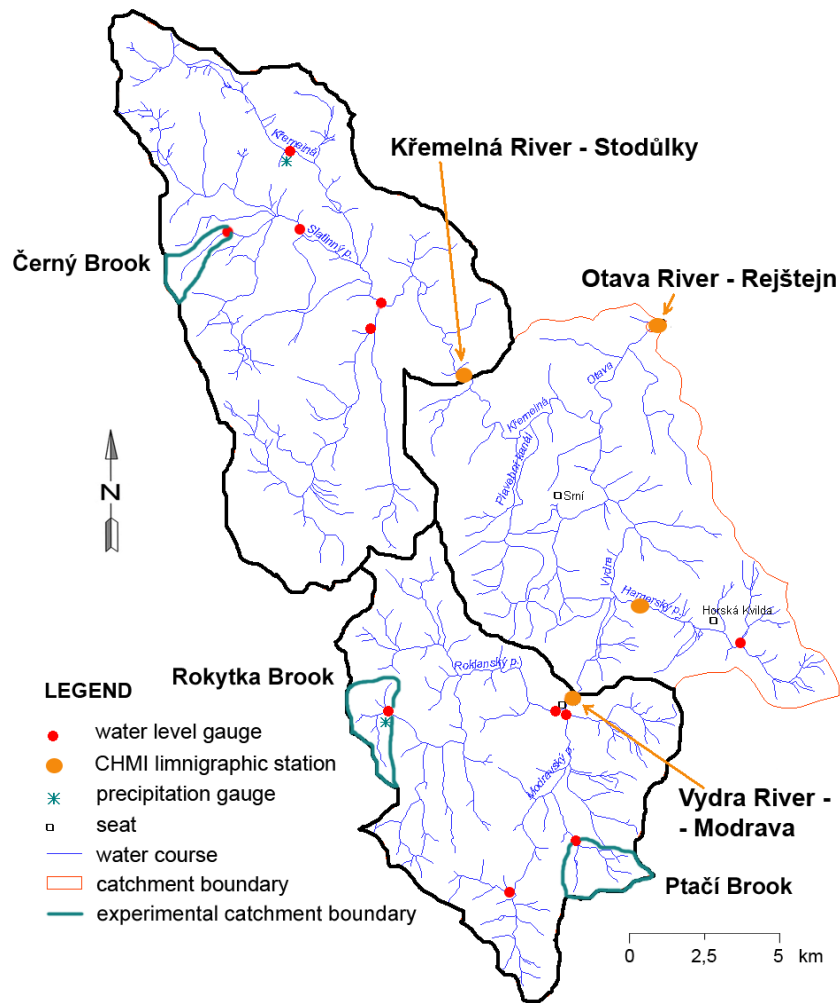


Figure 1. Localization of Vydra River and Křemelná River study basins with the contour accentuation of their closing profiles within the CHMI basic network of limnigraphic stations.

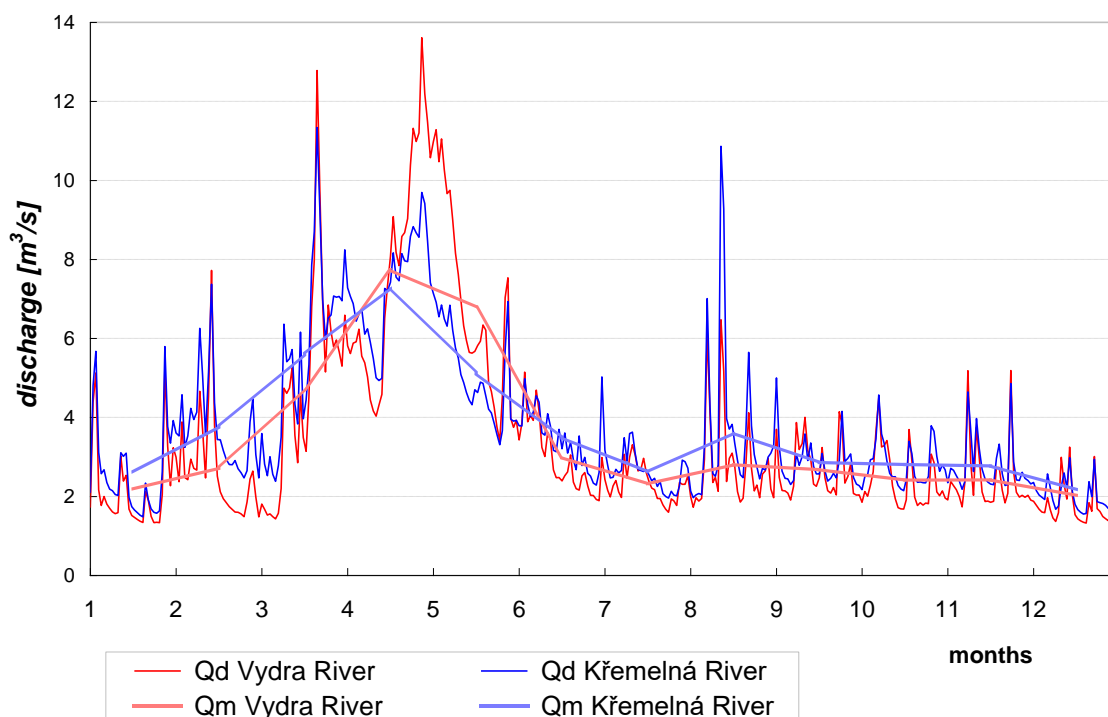


Figure 2. Long-term mean daily (Q_d) and monthly discharges (Q_m) in Vydra River - Modrava and Křemelná River - Stodůlky profiles in November 1, 1999 - October 31, 2006 period.

profile	Vydra River - Modrava	Křemelná River - Stodůlky
catchment area [km^2]	90,17	134,11
long-term mean discharge [m^3/s]	3,483	3,722
minimum discharge [m^3/s]	0,763	0,880
maximum discharge [m^3/s]	55,1	64,6
specific discharge [$\text{l}/\text{s}/\text{km}^2$]	38,5	27,8
minimum specific discharge [$\text{l}/\text{s}/\text{km}^2$]	8,5	6,6
maximum specific discharge [$\text{l}/\text{s}/\text{km}^2$]	611	482
yearly discharge volume [km^3]	0,1098	0,1174
height of discharge [mm]	1218	875
median	2,03	2,41
dispersion	15,859	15,153
mean divergence from mean value	2,471	2,405
authoritative divergence	3,982	3,893
decil divergence (Q_d)	0,601	0,502
coefficient of variability C_v (Q_d)	1,143	1,046
coefficient of variability C_m (Q_m)	0,421	0,392
monthly discharge variability coef. K_r	5,048	3,686

Table 1. Runoff variability characteristics in Vydra River - Modrava and Křemelná River - Stodůlky profiles (November 1, 1999 - October 31, 2006 period).

3.2 Runoff variability in experimental catchments

In consequence of present short period of water level fluctuation monitoring using automatic water level gauges only partial results are kept at disposition. Preview of one of our outcomes from ultrasound water level gauge and shuttle precipitation gauge is presented in the fig. 3. It shows the discharge fluctuation of Rokytká Brook (Vydra River headstream area) in relation to the amount of precipitation in October 1, 2006 - May 20, 2007 period. Significant discharge increase during spring period as a result of snow melting process in the catchment is very distinct. Nevertheless striking runoff fluctuation (between 0,2 and 0,5 m³/s) was registered also within the day.

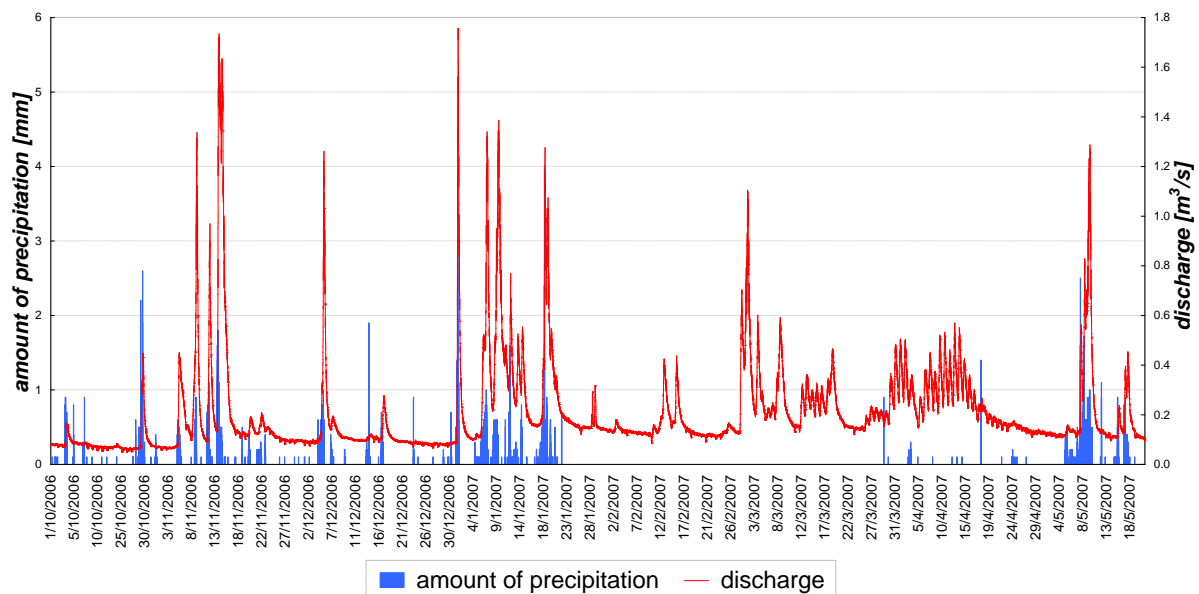


Figure 3. Partial outcome from automatic ultrasound water level gauge and shuttle precipitation gauge – runoff reaction to causal amount of precipitation in Rokytká Brook profile (Vydra River headstream area) in October 1, 2006 - May 20, 2007 period (in January 1, 2007 - March 28, 2007 period precipitation gauge was out of service).

As it was mentioned, in order to assess peatbog localities influence on runoff regime variability two subcatchments within the upper Otava River study catchment with very different peatland proportion were chosen. In the upper part of Rokytká Brook Catchment closed by the profile with installed water level gauge a large complex of so called "Rokytecké Moors" is situated (approximately 55% peatland proportion; fig. 4). Much more sporadic occurrence of peatbog beds is fixed to the Zhůrecký Brook Catchment (about 6% peatland proportion) in Křemelná River headstream area. Slightly higher runoff variability in the case of Rokytká Brook is quite distinct from fig. 5. In doing so, discharge variability is besides absolute value of culmination defined especially by a peak flow frequency. Different rate of discharge of both water courses in monitored profiles is taken into account using Q/Q_p ratio, where Q is actual 10-minutes discharge and Q_p is mean discharge from the serie of all 10-minutes discharges from the whole monitoring period.

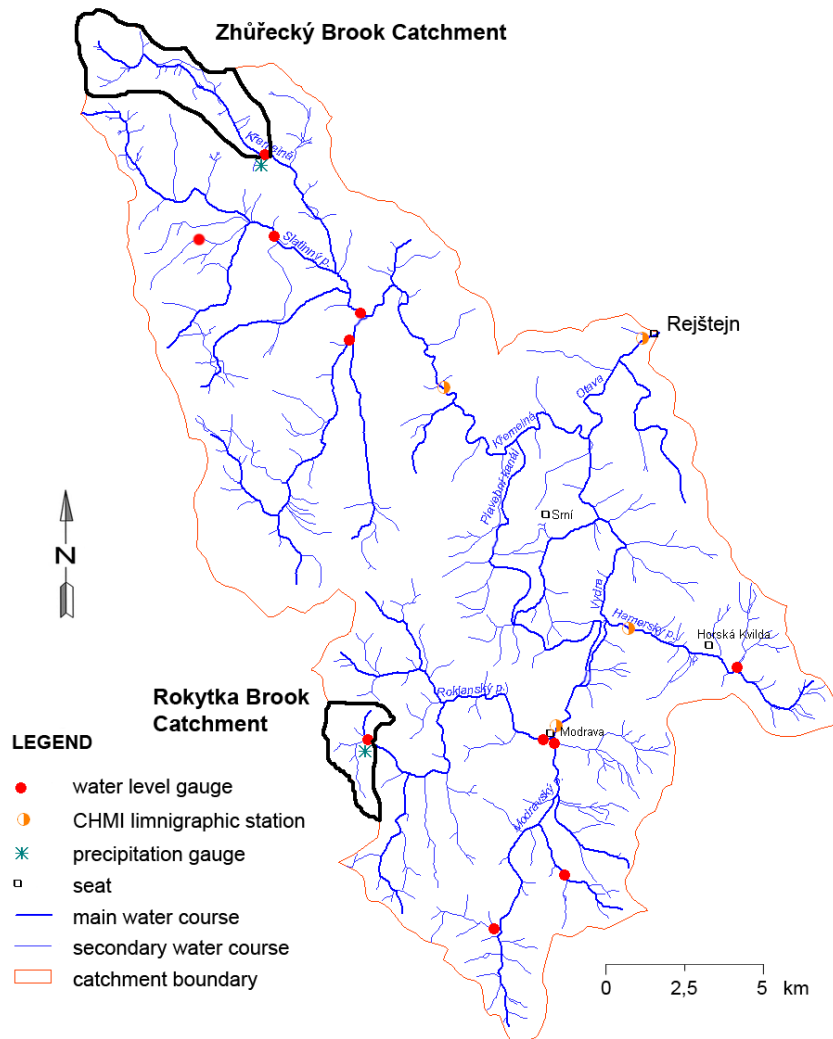


Figure 4. Localization of automatic water level gauges, shuttle precipitation gauges, CHMI limnigraphic stations and experimental catchments within the headstream area of Otava River.

Through the exact study of runoff ascending and descending phases, concretely through the analysis of runoff reaction to causal rainfall (interval between maximum 10-minutes amount of precipitation and corresponding peak flow) during several rainfall situations within the monitoring period, more significant peak flow retardation in Zhůřecký Brook profile (about 4:40 hours in average) compared to Rokytka Brook profile (about 3:20 hours) was determined. It signifies higher water retention potency in the catchment with distinctively lower peatland proportion. Mentioned claims necessarily demand stronger reliance in terms of longer data time series and detailed analyses of a larger number of namely extreme rainfall situations.

To sum it up, detailed analyses of extreme runoff phases show higher frequency of peak flows and their shorter reaction to causal rainfall in case of highly peaty areas, therefore more distinct runoff variability of streams draining peatland localities. Continuously much more detailed studies of hydrological and climatic data time series need to be done, especially reaction analyses of runoff from several peatbog localities in relation to rainfall duration, intensity and spatial distribution in monitored catchments by means of thorough study of its ascending and descending phases.

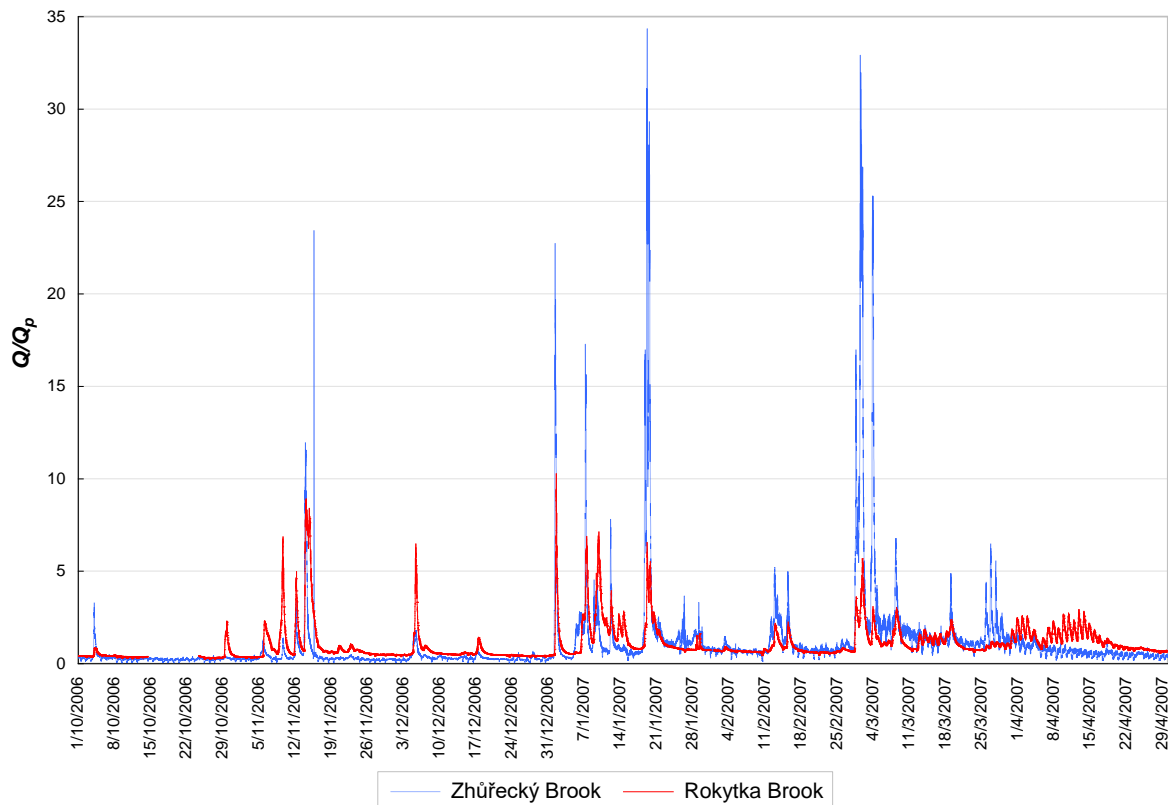


Figure 5. Comparison of runoff variability in two catchments with a different peatland proportion (Rokytká Brook, Zhůrecký Brook) in October 1, 2006 - April 30, 2007 period.

3.3 Extreme flood event analysis in model catchments

In order to compare the runoff conditions of areas with different physical-geographic parameters during an extreme runoff situation, flood event at the beginning of March 2008 was partly analysed in three experimental catchments. Their choice was concentrated mainly on the peatland proportion in the catchments. To reach the goal, within these three localities one catchment with very high proportion of peaty areas (Rokytká Brook; approx. 55%) and one with very low value (mineral Černý Brook catchment; about 5%) were chosen. The distribution of moor areas within the basin of Ptačí Brook is around average (see fig. 1).

The extreme amount of precipitation which affected a large territory of Europe early this year, known as Emma atmospheric low pressure, became very intensive especially in this study area. The runoff reaction on such an extreme rainfall totals in headwaters is generally very rapid and is demonstrated even by the graph in fig. 6. Water level fluctuation in three study profiles with installed automatic gauges for discharge monitoring quite apparently show very similar references mentioned above in the paper - higher runoff variability in the case of highly peaty area, even during such an extrem hydrological situation. The corresponding discharge values calculated using consumption curves (fig. 7) in two out of three profiles is even more evident (see fig. 8). The existence of periods with missing discharge data is caused by an enormous extremity of this event.

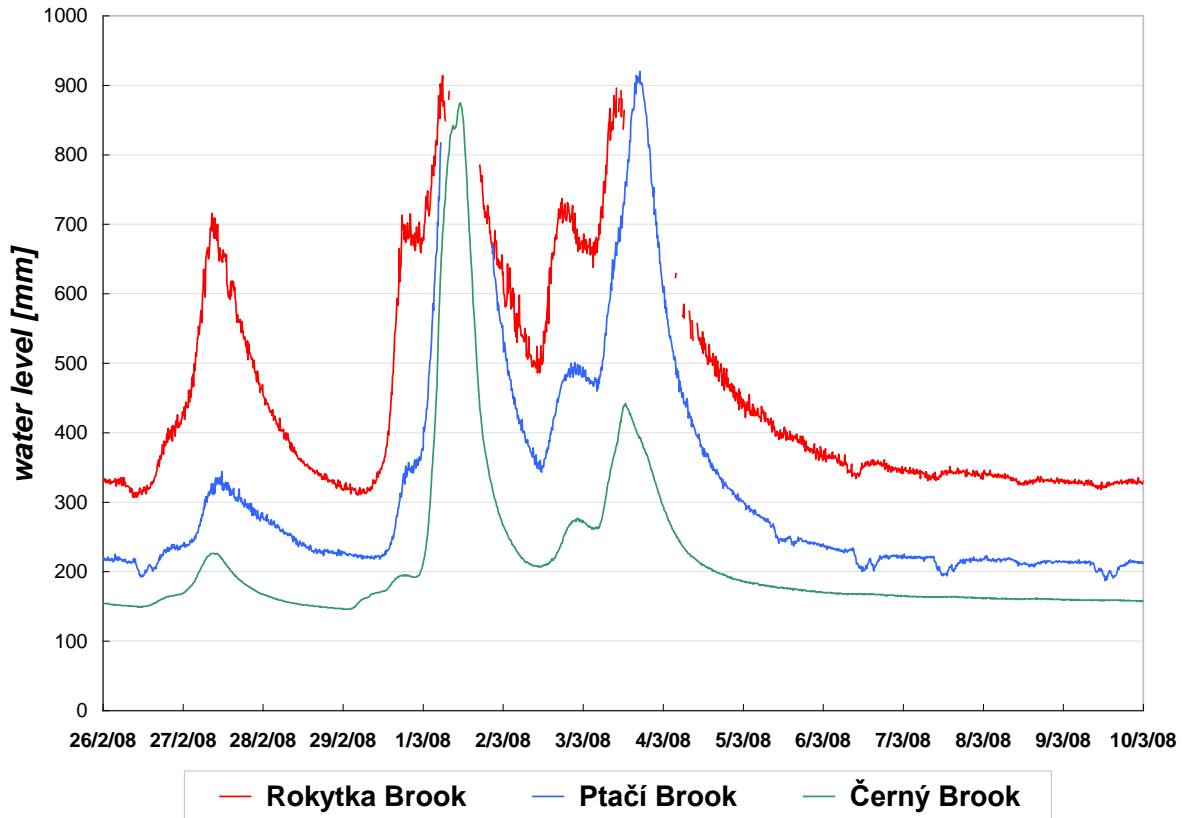


Figure 6. Water level fluctuation in three model catchments during the extreme flood in March 2008.

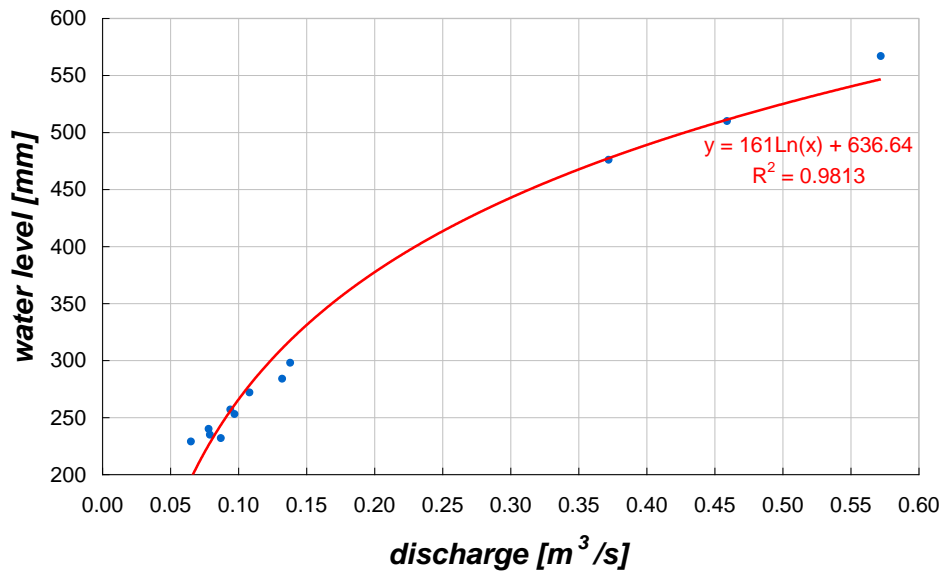


Figure 7. Consumption curve in the Rokytká Brook profile.

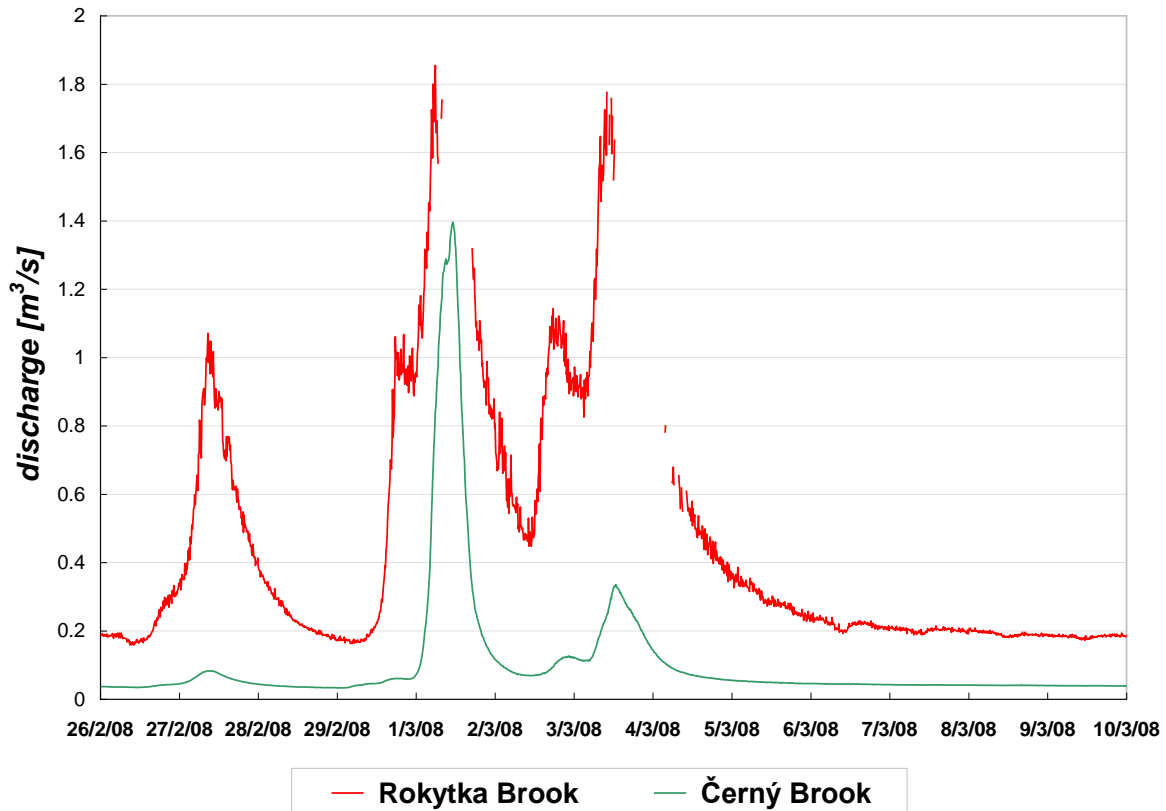


Figure 8. 10-minutes discharges in two experimental catchments with very different peatland proportion during the extreme flood event in March 2008 (highly peaty area is represented by Rokytka Brook catchment).

4 CONCLUSIONS

All of the issues related to various possibilities and measures leading to river headstream areas retention capacity increase should be discussed by experts in various fields taking into account objectives and priorities of a regional and local significance (Buček, 1998; Knapp, 2000; Kolečka, 2003). Such a discussion could result for example in the introduction of suitable landscape elements or gradual modification of land use in areas playing various roles within the flood control (Kovář, Sklenička, Křovák, 2002). However, this cannot be applied to national nature reserves that should be left free of any human interventions.

Present outcomes from automatic water level gauges installed in the study catchment of upper Otava River persuade us of the fact that data measured this way make it possible to assess peatbogs hydrological function very in detail. Especially comparison of those parts of catchment where revitalizing measures took place, respectively other parts where ameliorative adjustments of mountainous peatbogs were implemented in the last 70s, needs to be carried out. Continual records of water level and corresponding discharge values offer an extraordinary database for detailed analyses of flood waves ascending and descending phases, respectively for assessment of peatbogs influence on runoff process during dry periods. Qualified conclusions from field survey can be formulated after analyses of longer data time series. Nevertheless, partial outcomes from present studies quite conclusively present more distinct runoff variability in profile closing catchment with very

significant peatland proportion mainly with respect to higher frequency of peak flows. Negative effect of peatbog localities on river headstream area hydrological regime was confirmed by thorough study and comparison of runoff reaction to causal rainfall total in both experimental catchments as well. Longer reaction interval diverting to more significant causal rainfall amount retention in the catchment was determined in the case of the catchment with less peatland proportion.

The problem of peatbogs hydrological function depends on a number of factors, especially on its type, health state, rate of anthropogenic impact, etc. The assessment of peatland hydrological regime and considering the influence of chosen physical-geographic factors is currently carried out. At present the determination of peatbog revitalizing measures influence on their runoff regime is in process. The peatland influence on hydrological regime is being considered also with respect to the ionic content and carbon and oxygen isotopes balance of water in periods of low or high discharges. In addition to considering dyking of former drainage channels and focusing on recovery of vegetation health state having a positive influence on retention capability in the catchment we should also evaluate possible former accumulation reservoirs (used for wood floating) restoration with potential function as dry polders (Janský, 2006). Using complex system of hydrological models the simulation of runoff process and assessment the effectiveness of these reservoirs could be made. Implementation of such unforceable measures could contribute to reduction of peak flows and to increase of water resources during extreme droughts in future. The implementation of mentioned profiles with installed automatic gauges within the flood warning system in cooperation with CHMI is cogitated.

ACKNOWLEDGMENTS

The presented research was funded by the project VaV SM/2/57/05 "Long-term Changes of River Ecosystems in Floodplains Affected by Extreme Floods", Research Plan MSM 0021620831 "Geographical Systems and Risk Processes in Context of Global Changes and European Integration" of the Czech Ministry of Education and the Charles University Grant Agency project No. 2371/2007 "Water Retention in River Headstream Areas as an Instrument of Integrated Flood Protection and Drought Problem Solving".

References

- Baird, A. J. (1997): Field estimation of macropore functioning and surface hydraulic conductivity in a fen peat. *Hydrological Processes* 11, s. 287-95.
- Buček, A. et al. (1998): *Analýza povodňových událostí v ekologických souvislostech*. Unie pro řeku Moravu, Brno, 81 s.
- Burke, W. (1967): Principles of drainage with special reference to peat. *Irish Forestry* 24, s. 1-7.
- Conway, V. M., Millar, A. (1960): The hydrology of some small peat-covered catchments in the northern Pennines. *Journal of the Institute of Water Engineers* 14, s. 415-24.
- Ferda, J. (1960): Hydrologický význam horských vrchovištních rašelinišť. *Sborník ČSAZV – Lesnictví*, č. 10, Praha, s. 835-856.
- Ferda, J., Hladný, J., Bubeníčková, L., Pešek, J. (1971): Odtokový režim a chemismus vod v povodí Horní Otavy se zaměřením na výskyt rašelinišť. *Sborník prací HMÚ*, sv. 17, HMÚ, Praha, s. 22-126.
- Holden, J., Burt, T. P. & Cox, N. J. (2001): Macroporosity and infiltration in blanket peat: the implications of tension disc infiltrometer measurements. *Hydrological Processes* 15, s. 289-303.
- Holden, J., Chapman, P. J., Labadz, J. C. (2004): Artificial drainage of peatlands: hydrological and hydrochemical process and wetland restoration. *Progress in Physical Geography* 28,1, s. 95-123.

- Huikari, O. (1963): Über den Einfluss der Grabenabstände auf den Wasserhaushalt der Torfboden in Sphagnum-Mooren, Verdunstung und Abfluss des Wassers. Ref. Intern. Torfkongress, Leningrad.
- Janský, B. (2006): Water Retention in River Basins, AUC Geographica, 38, č. 2, s. 173-183.
- Janský, B., Kocum, J. (2007a): Hydrologická funkce rašeliníšť. In: Langhammer, J. (Ed.), Změny v krajině a povodňové riziko. Sborník příspěvků semináře Povodně a změny v krajině. PřF UK a MŽP ČR, Praha, s. 173-182.
- Janský, B., Kocum, J. (2007b): Retenční potenciál v pramenných oblastech toků. In: Langhammer, J. (Ed.), Povodně a změny v krajině. MŽP ČR a PřF UK, Praha, s. 307-316.
- Knapp, R. (2000): Protipovodňová ochrana. Zátopová území řek Moravy a Bečvy. Geoinfo, 7, č. 6, s. 28-32.
- Kocum, J., Janský, B. (2007a): Retention potential in river headstream areas. Sborník příspěvků mezinárodního kurzu UNESCO Ecohydrological Approaches to Wise Use, Restoration, Management and Conservation of Wetlands. Třeboň, s. 8-16.
- Kocum, J., Janský, B. (2007b): Water retention in river headstream areas as an instrument of integrated flood protection and drought problem solving. Sborník příspěvků IUGG XXIV General Assembly Earth: our changing planet. USMA, Perugia, Italy, s. 887.
- Kolejka, J. (2003): Geoekologické aspekty zmírňování povodňových škod. Geografie – Sborník ČGS, roč. 108, č. 1, Praha, s. 1-13.
- Kovář, P., Sklenička, P., Křovák, F. (2002): Vliv změn užívání krajiny na její ekologickou stabilitu a vodní režim. In.: Extrémní hydrologické jevy v povodích. ČVUT a ČVVS, Praha, s. 99-106.
- McDonald, A. (1973): Some views on the effects of peat drainage. Scottish Forestry 27, s. 315-27.
- Moklyak, V. I., Kubyskin, G. P. & Karkutsiev, G. N. (1975): The effect of drainage works on streamflow. Hydrology of marsh-ridden areas, Proceedings of the Minsk symposium, June 1972. IAHS Studies and Reports in Hydrology, 19. Paris: Unesco Press, s. 439-46.
- Novák, M. (1955): Huminové vody ve vodách údolních nádrží. Vodní hospodářství č. 4, s. 127-128.
- Novák, M. (1959): Výzkum kvality vody v údolní nádrži Lipno. Vodní hospodářství, r. 9, č. 9, s. 378-383.
- Onderíková, V., Štěrbová, A. (1956): Príspevok k biológii a chemizmu Oravskej nádrže. Vodní hospodářství, r. 6, č. 2, s. 46-51.
- Oulehle, F., Janský, B. (2003): Limnologie a hydrochemismus v NPR Rejvíz. In.: Jezera České republiky (Současný stav geografického výzkumu). Monografie na PřFUK Praha, s. 93-108.
- Robertson, R. A., Nichol, I. A., Hughes, R. (1963): Studien über den Abfluss eines Moores. Ref. Intern. Torfkongress, Leningrad.
- Vidal, H., Schuch, M. (1963): Ergebnisse vergleichender Abfluss und Grundwasserbeobachtungen auf einer unberührten bzw. kultivierten Hochmoorfläche in den südlichen Chiemseemooren im Abflussjahr 1962. Bayer. Landw. Jahrbuch 40, H. 6, s. 721-736.