Hydrological regime and physico-chemical water properties of various types of peat bog sites: case study of Mezilesní peat bog, Šumava Mts.

TOMÁŠ DOLEŽAL[1], LUKÁŠ VLČEK[1], JAN KOCUM[1,2], BOHUMÍR JANSKÝ[1]

[1] Charles University, Faculty of Science, Department of Physical Geography and Geoecology, Prague, Czechia; e-mail: dolezat2@natur.cuni.cz, lukas.vlcek@natur.cuni.cz, jan.kocum@natur.cuni.cz, bohumir.jansky@natur.cuni.cz

[2] Technical University of Liberec, Faculty of Science, Humanities and Education, Department of Geography, Liberec, Czechia

ABSTRACT In a period with frequently occurring hydrological extremes, research on areas with a high retention potential is brought into focus. The Šumava Mountains peat bogs are important parts of the landscape in the headwater area of the Otava river basin. The study objective is to describe the variability of discharges and the dynamics of groundwater level changes in various types of peat bogs, and to identify connections between observed physico-chemical water properties. This is assessed by basic statistical methods. The rainfall-runoff process and physico-chemical water properties can be affected by many factors. In this case, strong relations between the observed parameters were identified along with considerable differences in the involvement of various types of peat bog sites in the runoff process. It is evident that the peat bog pattern and its vegetation cover have an essential effect on the hydrological regime and water properties stored in a peat bog.

KEY WORDS peat bog – Šumava Mts. – groundwater level – hydrological regime – headwater area

DOLEŽAL, T., VLČEK, L., KOCUM, J., JANSKÝ, B. (2020): Hydrological regime and physico-chemical water properties of various types of peat bog sites: case study of Mezilesní peat bog, Šumava Mts. Geografie, 125, 1, 21–46.
https://doi.org/10.37040/geografie2020125010021
Received March 2019, accepted November 2019.

1. Introduction

The headwater areas of streams represent resource areas for runoff formation. These areas are very heterogeneous in terms of their physical-geographical and rainfall-runoff aspects. The existence of important areas of peat bog complexes, an ecological phenomenon of local landscape, constitutes an important special characteristic of the Czech part of the Šumava Mts. It is therefore essential, in a specific territory of the headwater area of the Otava river, to deal with the effect of this phenomenon on hydrological regime and runoff formation (Kocum 2012; Čurda, Janský, Kocum 2011). The peat bogs have an important effect on hydrological processes in the landscape (Janský, Kocum 2008). The water storage capacity of the soil is one of the most important water retention components in the landscape. The physical properties of the soil and its general condition are the main factors controlling infiltration into the soil during precipitation events or the length the water can be stored in peaty soil during dry periods (Vlček et al. 2012, Vlček 2017). In the case of the Šumava Mts., the anthropogenic influence on the water regime of peat bogs that were drained in the past or even extracted is also an important factor. Particular interventions are currently being produced by means of restoration measures and blocking up of drainage ditches (Doležal et al. 2017).

Acrotelm plays the most important role in hydrological processes of a peat bog. It is a thin living surface layer of peat-forming vegetation, generally between 10 cm and 40 cm deep, relatively inert. Without acrotelm a bog cannot accumulate peat or control water loss from the deeper layer (Lindsay, Birnie, Clough 2014). The research of peat bogs in the Šumava Mts. is mostly focused on variability of the groundwater level (GWL) in the peat bog, depending on vegetation, or mitigation of anthropogenically disturbed water regime. For example, a research on the peat bog at Schachtenfilz (Bavarian side of the Šumava Mts.) proved that the GWL reached on average higher values in shrub vegetation on an open bog and in waterlogged forest. The GWL on a peat bog covered by grasslands with cottongrass showed greater variation (Bufková, Stíbal 2012). A substantial relationship between the type of vegetation and the GWL is also mentioned by Kučerová, Kučera, Hájek (2009). Vegetation is very responsive to changes of the water regime. A long-term decline or rise can cause succession changes. After longer periods without precipitation, sphagnum mosses become dry; the albedo changes cause decrease in evaporation and increase of surface temperature.

The GWL in many types of peat bogs has a considerable seasonal dynamics. A relatively stable level is found only in peat bogs saturated with source of artesian water. On the contrary, ombrotrophic bogs that are entirely dependant on precipitation, usually show high variability of GWL and considerable GWL decline during summer. The variation of the hydrological and hydro-chemical regime of peat bogs can also be demonstrated by an increased dynamics of soil temperatures in the acrotelm layer. In particular, it is subsequently reflected in the temperature of the water running off from the peat bog (Puranen, Mäkilä, Säävuori 1999).

In terms of the hydro-chemical properties of peat bog water, considerably negative correlations between the GWL and pH were identified; i.e. it was found that water deficiency in the catchment causes an increase in pH, although this research refers rather to river floodplains and transitional mires (Bufková, Prach 2006). A similar dependence between water quantity and pH, for the Šumava Mountains' streams supplied by peat bogs, was observed by Prokš (2010). The water in the Šumava Mountains' peatlands as well as precipitation have usually a low quantity of dissolved substances; the pH values are in particular determined by the dissolved organic carbon concentration, which has a strong seasonal progress related to evaporation and organic matter production. A higher content of organic matter along with low total mineralization naturally result in low pH (Kocum 2012). The interventions to the water regime of peat bogs can also be accompanied by considerable changes in hydrochemism, in particular due to changes in PO_4, Al, Fe concentrations and electric conductivity (Bufková, Stíbal 2012). These studies indicate a connection between the hydro-chemical properties and the quantity of water in the catchment; however, a comprehensive research on the mountain bogs of the Šumava Mts. to compare these water parameters in the catchment has not been carried out yet. Important aspects of the research on physico-chemical water properties concerning peat bogs are the measurements of changes in the electric conductivity and water pH in the stream. In general, the electric conductivity changes with the quantity of contained ions. In terms of cations, Mg, K, Na, but also Fe, Mn or Al occur the most frequently. In the case of very low pH, higher values of electric conductivity can be caused by free hydrogen anions (Worrall, Burt, Adamson 2006).

Studies on the Šumava Mts. comply with the general view of the world literature and prove that the development of peat bog complexes is controlled mainly by hydrological processes. The formation of peat bogs depends mainly on the water storage capacity, on water quantity, its origin and chemical properties. The main factor in the development of peat bog complexes is the GWL as it determines the composition of species of the site (Labadz et al. 2010). Thus, the depth of the GWL determines the balance between organic matter accumulation and decomposition, and therefore even minor changes in the water regime can have an essential effect on development of peat bog complexes (Holden, Chapman, Labadz 2004). Wilson et al. (2011) indicate a strong relationship between the type of vegetation and GWL stability in a peat bog. A higher vegetation cover also results in improvement of the self-regulating process of peat, as the evaporation is reduced due to the higher level of air moisture maintained.

Lots of studies also discuss the issue of the effect of drainage and peat extraction on the water regime and hydro-chemical water properties (Bufková, Stíbal

2012; Holden et al. 2011; Holden, Chapman, Labadz 2004). Anthropogenic disturbance of the water regime due to extraction or drainage can cause irreversible changes in the physical properties of peat (Evans et al. 1999). The GWL is mostly affected by the amount of precipitation, evapotranspiration, by topography and also, locally, the peat porosity and hydraulic conductivity (Wilson et al. 2011; Allott et al. 2009). Holden et al. (2011) point out that the long-term low GWL in drained peat bogs could lead to negative processes in peat. If the GWL is too deep below the surface, oxygen enters the lower layers of the peat bog, which results in peat decomposition. This process subsequently causes changes in the porosity, hydraulic conductivity and runoff characteristics (Allott et al. 2009; Joosten, Clarke 2002). The study by Wind-Mulder, Rochefort, Vitt (1996) concluded that peat bogs affected by extraction showed very low pH values and also a high variability of pH in comparison with intact peat bogs.

Ombrotrophic bogs saturated with rainwater have relatively stable hydro-chemical properties. However, this does not necessarily hold true for the whole bog, e.g. a lagg area (the zone of transition between an ombrotrophic bog and the mineral soils of the surrounding landscape) has variable hydro-chemical properties as it is affected by water from surrounding mineral soils. The influence of mineral water from the surroundings on a peaty soil depends also on its pH, electric conductivity and on the amount of dissolved calcium and carbonates (Howie, Meerveld 2011). Water from peat bogs is acid, and its pH usually ranges between 3.3–5.5, while transitional mires show higher pH ranging approximately from 4.5 to 6. However, the abovementioned values depend on several factors, e.g. climate, the height of the GWL or biological activity (Bergsma, Quinlan 2009; Holden, Chapman, Labadz 2004). Another important water parameter, regarding the study of peat bogs, is electric conductivity. Electric conductivity measurement in the field shows very variable values, from several units to hundreds $\mu S.m^{-1}$. The electric conductivity correlates linearly with the amount of substances dissolved in water. In addition, the conductivity is strongly affected by the soil temperature and peat properties such as the cation exchange capacity of the soil, organic components, peat porosity, pH and soil moisture (Ponziani et al. 2011). Another important parameter of water, which is often monitored in peat bogs, is the dissolved oxygen that is necessary for aerobic respiration at all trophic levels. Oxygen gets into water by means of diffusion from the atmosphere, water mixing and as a product of aquatic organisms. In terms of oxygen solubility, the water temperature is an important factor. In cold water, oxygen is dissolved more easily (O'Driscoll et al. 2016).

The main objectives of the study include:

a) Characteristics of dynamics of GWL and discharges of various types of peat bog sites.
b) Characteristics of physico-chemical properties of surface water and groundwater of various types of peat bog sites.

c) Assessment of statistical dependences of physico-chemical properties of surface water and groundwater in peat bog on the water quantity in the catchment.

2. Site description

The Mezilesní peat bog belongs to the geomorphological district of Kvildské Pláně. This peat bog is situated in the headwater area of the Hamerský brook, which is the right-side tributary to the Vydra river (Fig. 1). It is situated at an altitude of approximately 1,100 metres. The area of the whole peat bog complex is 83 ha large and the peat volume is 1,649 million m³ (Anděra, Zavřel 2003).

In terms of mean monthly discharges, the minimum discharges are reached in February (in the period prior the snow cover melts) or in September (in the late summer, dry period). The best water-rich period is in spring during snowmelt. In this period, peat bogs in the Šumava Mts. are usually fully saturated. In summer

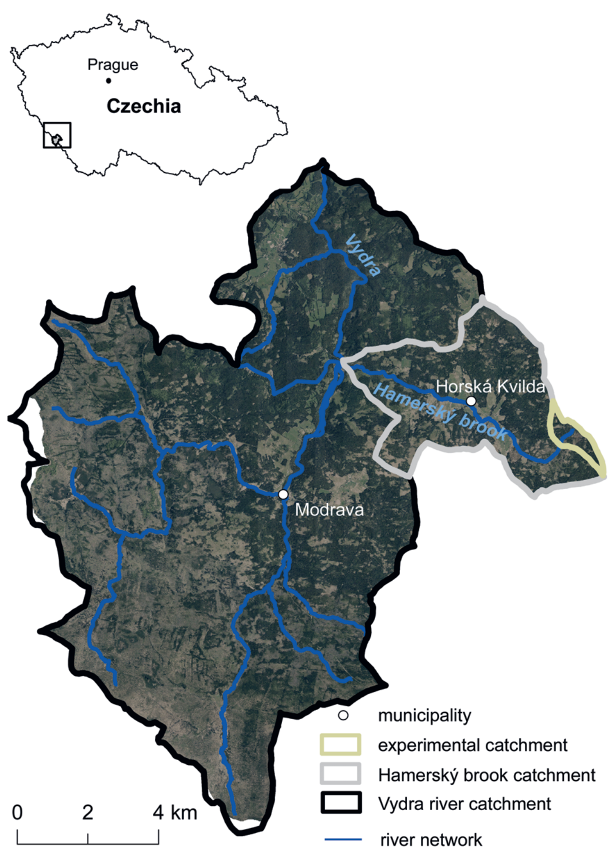


Fig. 1 – Catchment of the Vydra river with designation of the Hamerský brook and experimental catchment in its headwater area

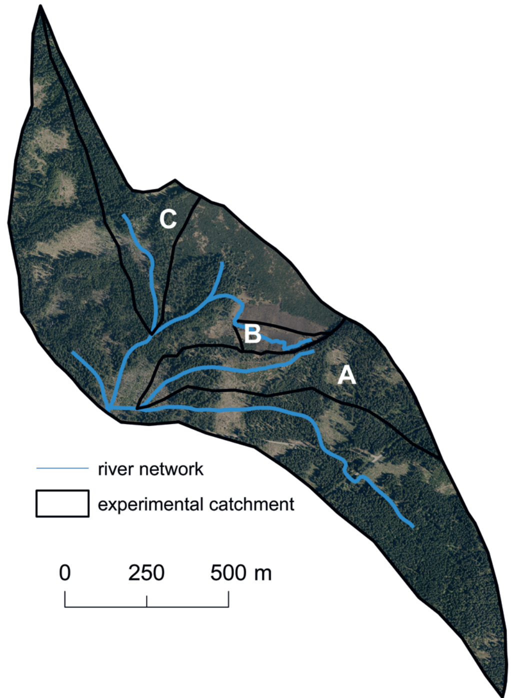


Fig. 2 – Headwater area of the Hamerský brook with designation of experimental catchments

months, discharges show a high variability, which is in particular caused by short periods of intensive precipitation. The value of mean annual precipitation in this region is approximately 1,100 mm (Kocum 2012). In the monitored area, there are peat bogs on sites with a low mean annual air temperature, but during the day the temperature can show considerable amplitudes (Hojdová, Hais, Pokorný 2005).

The headwater area of the Otava river basin belongs to a soil region of Cambisols or Rankers with steep slope areas and a region of entic and haplic Podzols. In the headwater area, there are predominantly hydromorphic soils situated in flat parts of the catchment (Šefrna 2004). The headwater area of the Hamerský brook, where the three experimental catchments are located (Fig. 2), is characterized by the occurrence of hydromorphic soils and organic soils which switch in the forest environment to entic Podzols and Gleysoils with acid pH reaction. The reason for selection of these catchments was due to the fact that on a relatively small area within one peat bog complex, there are several minor catchments with different vegetation cover. The different vegetation composition could have an essential effect on the hydrological regime of the experimental sites due to the difference in evapotranspiration. There is also a large area without vegetation, with bare peat only.

The three experimental catchments cover a total area of 25.4 ha. The smallest basin is an extracted part of the peat bog (catchment B), which is formed mostly by bare peat (Table 1). Shrub is here represented by stands of bog-bilberry (*Vaccinium*

Tab. 1 – Basic vegetation characteristics of experimental catchments

Catchment	A	B	C
Catchment area (ha)	13.6	1.9	9.9
Stream length (m)	599.5	291.8	401.3
Watershed length (km)	2.3	0.7	2.4
Maximum altitude (m a.s.l.)	1,149	1,113	1,135
Minimum altitude (m a.s.l.)	1,092	1,100	1,095
Elevation difference (m)	57	13	40
Forest proportion (%)	67	1	78
Shrub and grass proportion (%)	33	43	22
Proportion of area without vegetation (%)	0	56	0

uliginosum), common heather (*Calluna vulgaris*) and in some places, where peat was disturbed by extraction, there are areas of tussock cottongrass (*Eriophorum vaginatum*) and various species of sedges (*Carex;* Křenová, Hruška 2012). Catchment A (Fig. 2) includes a lagg that is represented by shrubs of the same species as catchment B. In addition, it is enriched with stands of cowberry (*Vaccinium vitis-idaea*), common bilberry (*Vaccinium myrtillus*), bog cranberry (*Vaccinium oxycoccus*) *and various species of grasses*. The lagg in the upper parts, at a distance from the peat bog, passes gradually to waterlogged forest, formed mainly by Norway spruce (*Picea abies*). Catchment C with predominant waterlogged forest is also formed mainly by Norway spruce (*Picea abies*). A part of the catchment is represented by mountain bog with predominant dwarf mountain pine (*Pinus mugo*). The treeless places are mostly formed by shrubs or various species of sedges (*Carex*) and cranberries (*Vaccinium*).

3. Methodology

All measurements were performed during the growing season of 5th May–29th September 2018. Twenty-one field measurements were performed at weekly intervals. Campaigns were held in the period of high water saturation of the soil during the spring after snowmelt and also during a very dry period of hot summer respectively. Each experimental stream was fitted with a hydrometric profile and four tubes at a distance of 2 m and 5 m from the stream on both sides, in which the physico-chemical properties of water and the GWL were measured manually. All GWL values were measured as distance between surface and water level in the tube. Measuring points were selected so as to sufficiently represent each type of vegetation (Fig. 3).

Tube 1 is situated at a distance of 2 m from the left bank, tube 2 at a distance of 5 m from the left bank, tube 3 at a distance of 2 m from the right bank and tube 4

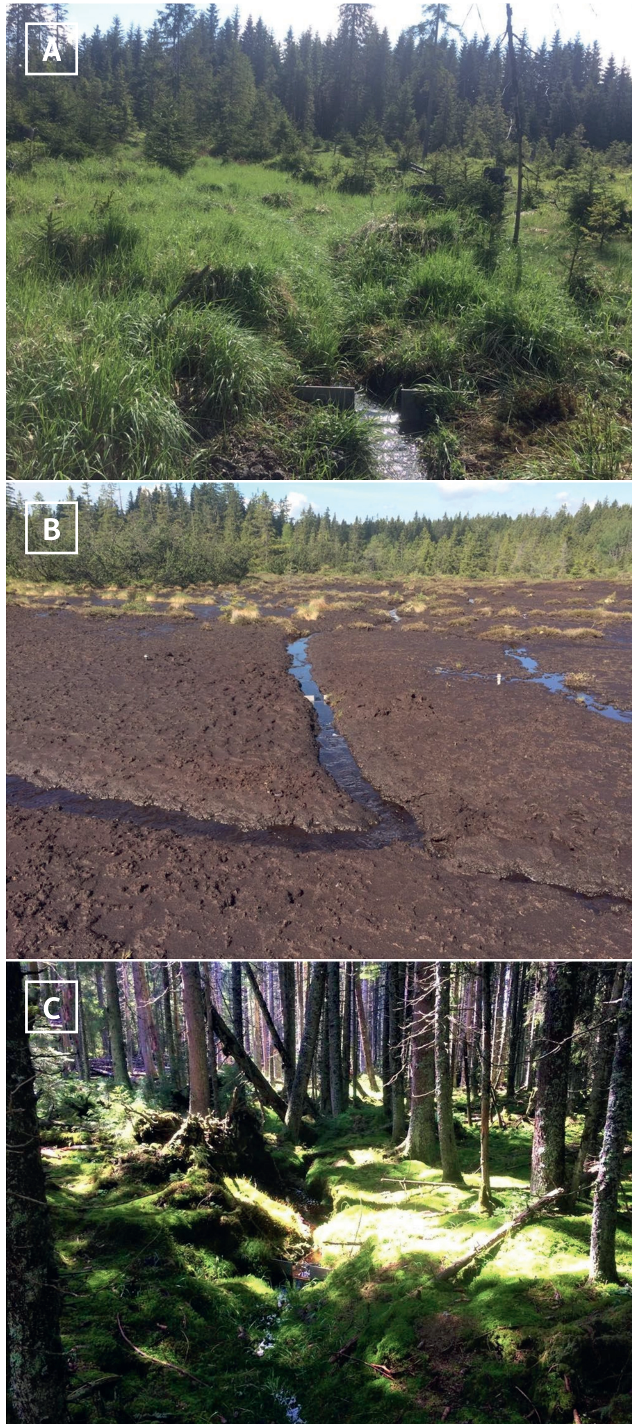


Fig. 3 – Vegetation cover in three experimental catchments. Catchment A – a lagg formed by grass, catchment B – an extracted part - bare peat, catchment C – waterlogged spruce forest. The experimental catchment and the streams are designated in the paper with letters A, B, C and the tubes are designated with numbers 1–4.

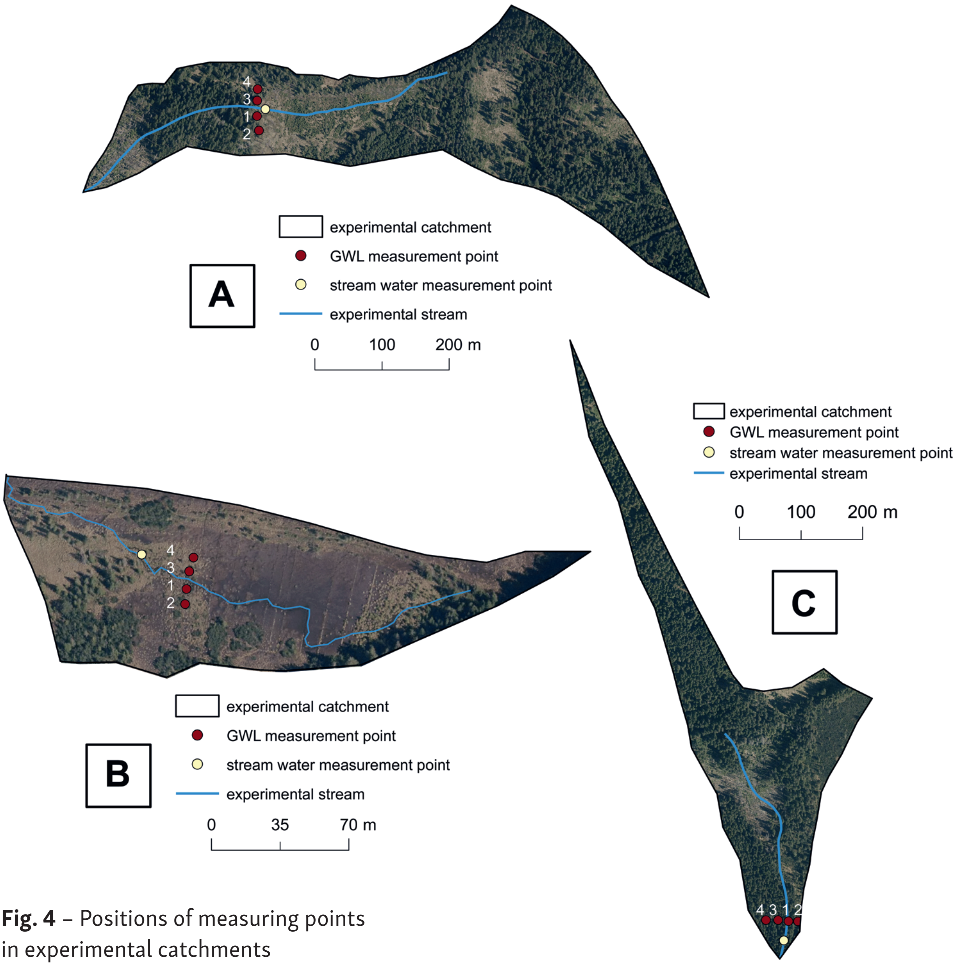


Fig. 4 – Positions of measuring points in experimental catchments

at a distance of 5 m from the right bank. This composition is identical in all three experimental catchments. The tubes and hydrometric profiles were installed as close as possible to the stream outflow from catchment so as to represent each type of vegetation as much as possible. Nevertheless, e.g. for catchment B, this was not possible due to surface factors, as in the lower part of the catchment, there are many minor depressions and the stream branches off to several small erosion furrows, terminating either in these depressions, or in a bog lake. In this case, an alternative site was selected upstream where it was possible to determine unambiguously the stream. In terms of catchment A, a small displacement was caused by a considerable change in vegetation cover in the catchment outflow (Fig. 4).

The measurements were performed episodically, using hand-held equipment. In this research, following parameters were observed: discharge, GWL, pH, electric conductivity, dissolved oxygen and water temperature. The parameters were measured in experimental streams (surface water) and experimental tubes (groundwater). The measurements of physical and chemical parameters of water were assured by calibrated field measurement systems, measuring within the range pH: 0–14, electric conductivity: 0–20,000 μS/cm, temperature: −35 °C to +135 °C and dissolved oxygen: 0–20 mg/l.

Discharges were measured by transmissible Poncelet weirs, which were calculated and adjusted according to parameters of monitored streams in growing season 2018. Discharges were calculated by Basin weir equation (Equation 1), using spillway-discharge coefficient for Poncelet weir (Equation 2):

$$Q = m.b.\sqrt{2.g}.h^{\frac{3}{2}} \tag{1}$$

$$m = \left[0.405 + \frac{0.003}{h} - 0.03\left(1 - \frac{b}{B}\right)\right][1 + 0.55)(\frac{b}{B})^2(\frac{S_0}{S})^2] \tag{2}$$

where *m* represents the spillway-discharge coefficient for Poncelet weir, *b* the length of the spillway crest, *g* the acceleration of gravity, *h* the falling height of water, *B* the length of weir, S_0 stream flow profile area, *S* area of spillway crest (Šráček, Kuchovský 2003). All data were subsequently analysed, using the statistical software StatSoft. Possible correlations between specific discharges, GWL and physico-chemical parameters were identified by calculations of Pearson correlation coefficients at the level $p < 0.05$.

The study also evaluates the dynamics of changes in the groundwater level in relation to precipitation and daily potential evapotranspiration (PET). The potential evapotranspiration was calculated by the Penman–Monteith equation (Equation 3).

$$PET_0 = \frac{0.408.\Delta.(Rn-G)+\gamma.\frac{900}{T+273.16}.u.(e_s-e_a)}{\Delta+\gamma.(1+0.34.u)} \tag{3}$$

where Δ represents the inclination of the water vapour saturation curve in connection with temperature [kPa.°C^{-1}], *Rn* the radiation balance [MJ.m^{-2}.day^{-1}], *G* the flow of heat into the soil [MJ.m^{-2}.day^{-1}], *ϒ* a psychometric constant [kPa.°C^{-1}], *u* the speed of wind [m.s^{-1}], (e_s-e_a) the saturation deficit of air at elevation *z* [kPa], and *T* the average air temperature [°C] (Penman 1948).

There is no meteorological station situated in experimental site. All meteorological data used in this paper were measured at the nearest automatic meteorological station at Modrava village, which is 8 km in a straight line.

4. Results

4.1. Water regime

Boxplots indicate (Fig. 5) that the widest range of specific discharges was observed for the stream representing an extracted part of peat bog (stream B). The stream B was the only one to show outliers and, in addition, it was completely dried out twice during the measuring period. High temperatures and direct solar radiation resulted in rapid peat drying. The most stable specific discharges were identified at the stream in waterlogged forest (stream C), which could be caused by high interception and lower evapotranspiration in comparison to other types of vegetation. The lagg (stream A) with its discharge values is rather similar to the extracted

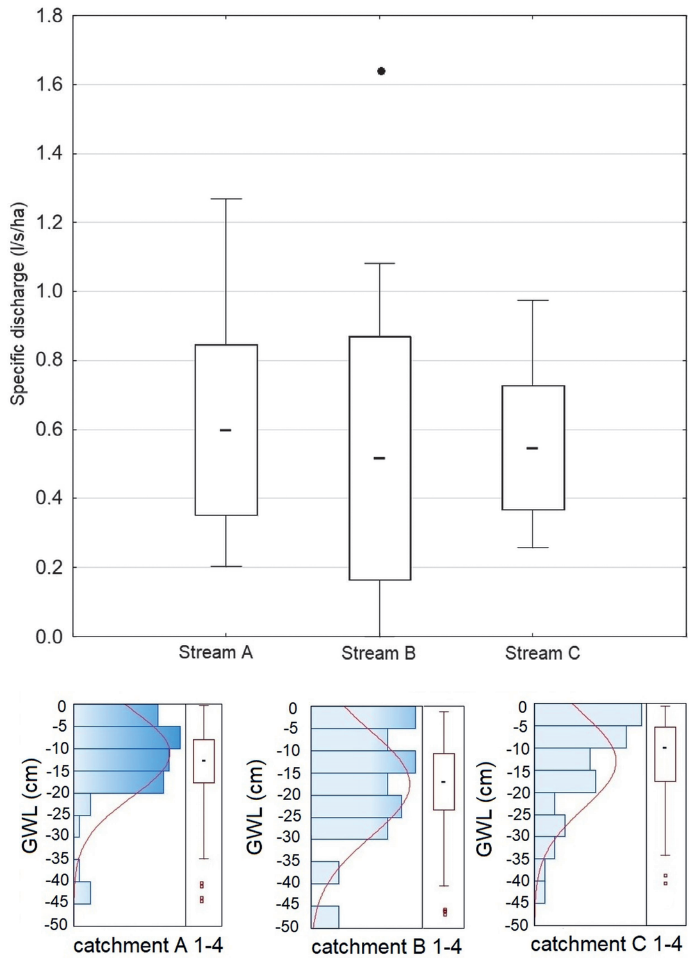


Fig. 5 – Distribution of measured values of discharges and GWL: stream (catchment) A – lagg, stream (catchment) B – extracted part of peat bog, stream (catchment) C – waterlogged forest. Numbers 1–4 designate the aggregate value of all measuring points of the GWL within the experimental catchment.

Tab. 2 – The basic statistical characteristics of discharges and GWL. Stream (catchment) A – lagg, stream (catchment) B – extracted part of peat bog, stream (catchment) C – waterlogged forest. Numbers 1–4 designate the aggregated value of all measuring points of the GWL within the experimental catchment.

Stream	A	B	C	Catchment	A 1–4	B 1–4	C 1–4
Number of measured values	21	21	21	Number of measured values	84	84	84
Average specific discharge (l/s/ha)	0.6	0.51	0.55	Average GWL (cm)	10.97	17.40	12.96
Minimum specific discharge (l/s/ha)	0.2	0	0.26	Minimum GWL (cm)	0	0.50	0
Maximum specific discharge (l/s/ha)	1.27	1.65	0.98	Maximum GWL (cm)	45.00	49.10	42.20
Range specific discharge (l/s/ha)	1.07	1.65	0.72	Range GWL (cm)	45.00	48.60	42.20
Standard deviation	0.25	0.35	0.18	Standard deviation	9.76	11.82	10.45
Coefficient of variance	41	68	33	Coefficient of variance	89	68	81

part; nevertheless, it does not show such considerable extremes. The quantity of measured GWL values in particular intervals was very similar in the forest and in the lagg. The extracted part showed a higher variance in the GWL.

The basic statistical parameters show that the highest variation of discharges was observed in the extracted part of the peat bog, which is confirmed by the standard deviation of flows and the variance (Table 2). In addition, high values of standard deviation and a low coefficient of variance of the GWL indicate the occurrence of considerable variations in the GWL. In this case it was proved that waterlogged forest does not have high variability of flows in comparison with other types of peat bog sites, because the range of measured values and their

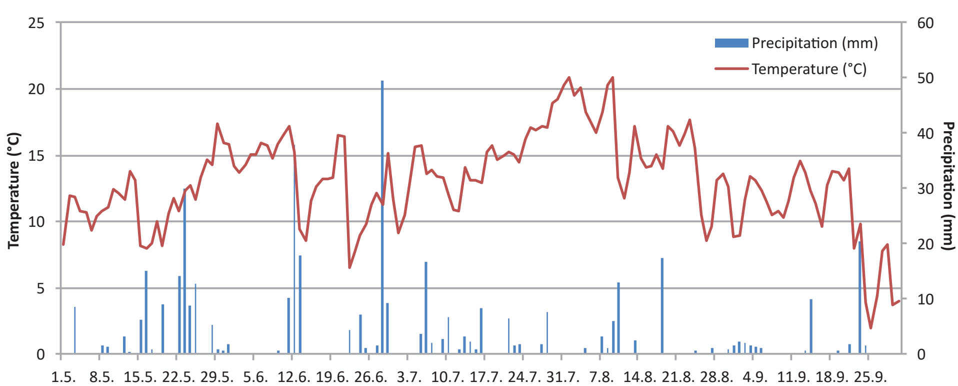


Fig. 6 – Regime of daily precipitation and mean daily air temperature in observed period

standard deviations are very low. In terms of the variability of values of the specific discharges and GWL, the lagg is situated in the middle of both mentioned types.

For a clear illustration of progress of GWL, precipitaton and air temperature in observed period were analysed (Fig. 6). During the summer there were high mean daily air temperatures, especially in late July and early August (over 20 °C). The total of precipitation in observed period was 422.1 mm, which represented approximately average growing season in the region. Maximum of daily precipitation was 49.5 mm (26th June). The highest monthly value of precipitation was in June (140 mm) and the lowest in September (43.8 mm). It is assumed that at the beginning of the growing season peat bog is fully saturated due to snowmelt.

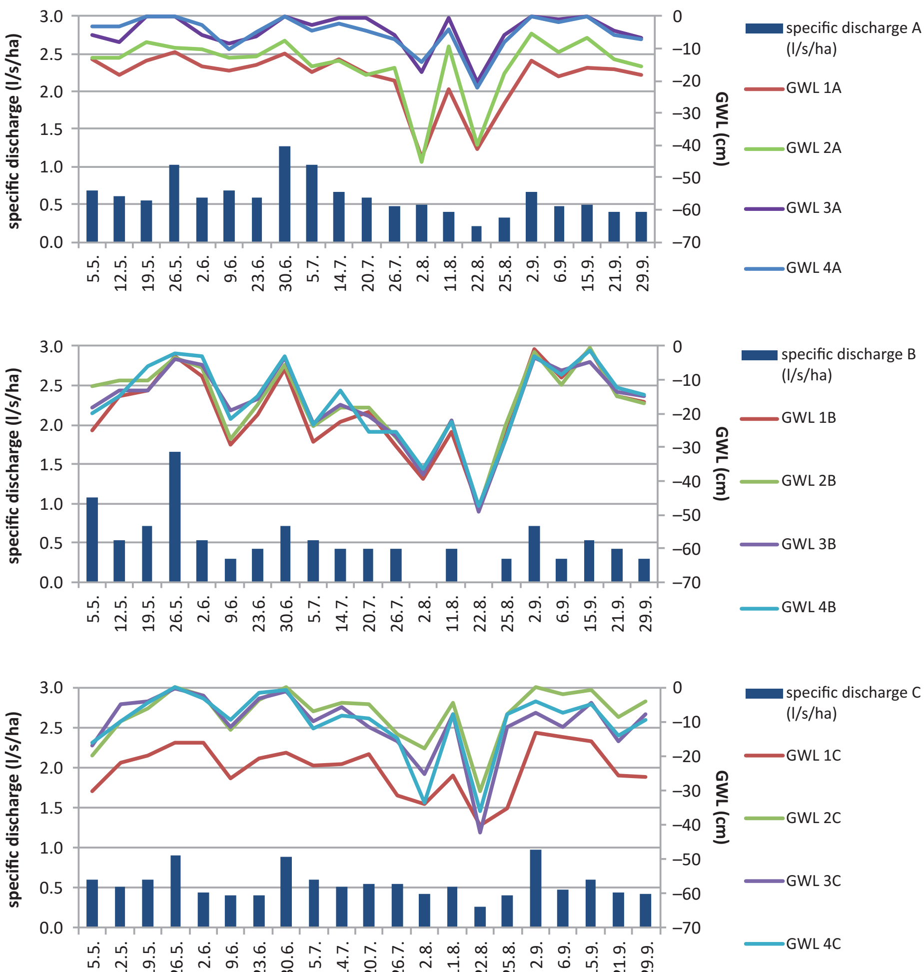


Fig. 7 – Specific discharges and GWL progress in experimental catchments

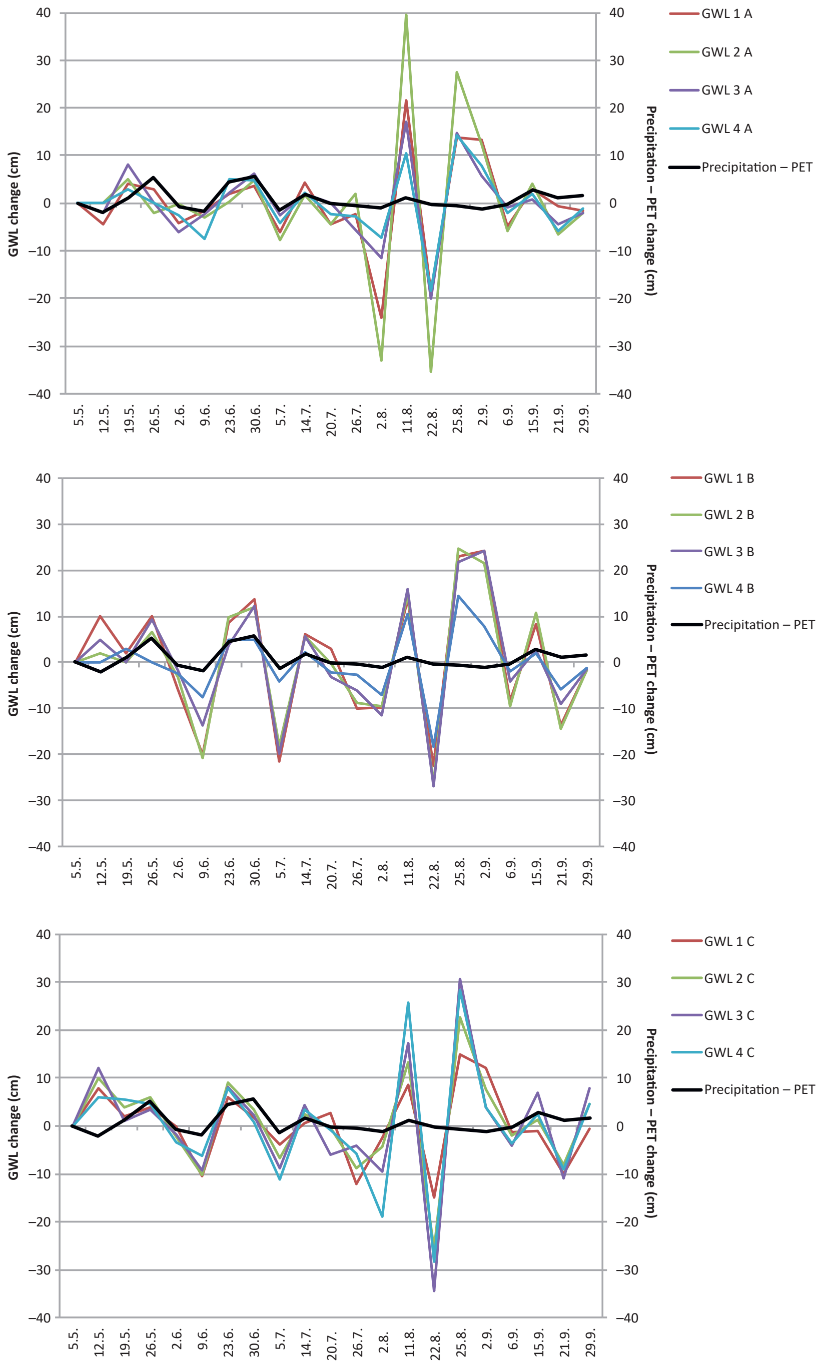


Fig. 8 – Differences in daily precipitation and PET and their comparison with differences in GWL between measurements within experimental catchments

The progress of the specific discharges and GWL within experimental catchments is shown in Figure 7. The charts show a higher variability of discharges in the extracted part of the peat bog, which probably relates to higher variability of the GWL. This fact also indicates that the distance of GWL measurement from the stream is not so important, because all measuring points of experimental catchment B show almost identical values during the whole measuring period. Stream C, in waterlogged forest, shows relatively high values of GWL (as in the case of the lagg). However, the values of the specific discharges are slightly lower, which is probably caused by the considerably more dense vegetation cover and thus by better surface cover of the peat bog complex. The importance of vegetation cover was probably also confirmed by the lower variance of extreme values in comparison with the lagg, both in the maximum and in the minimum flow.

The dynamics of changes in GWL depends mostly on meteorological factors. The differences of the precipitation and daily PET between campaigns in all catchments are very similar to the progress of changes in the GWL (Fig. 8). Catchment A shows the smallest average deviation of the difference in GWL and differences of the precipitation and PET. In this case, the average deviation is 6.4 cm, i.e. the other factors affecting the GWL do not probably have such a strong effect. In terms of catchment B, the average deviation reaches the maximum value of 8.3 cm, which indicates rapid changes in the GWL in the disturbed area of the peat bog. For the waterlogged forest, the average deviation reached the value of 7 cm. In addition, it is necessary to point out that the amount of deviations significantly increased by the four measurements in August, with very high deviations from the average in all catchments.

4.2. Physico-chemical water properties

The extracted part of the peat bog, which surface is not covered by any vegetation, shows the highest mean temperature and variability of the surface water temperature and groundwater temperature. In this case, the vegetation of lagg and waterlogged forest contribute identically to a decrease in temperature that is similar in both types of peat bog (Table 3). The values of dissolved oxygen in all catchments are very similar. The amount of oxygen reaches slightly higher values only in the groundwater of the waterlogged forest. The stream in the extracted part of the peat bog shows a very high electric conductivity. On the other hand, the comparison of values of the groundwater electric conductivity showed that similar values were measured in all experimental catchments. In the observed catchments, the pH reached highest values in the lagg, probably due to soil mineralization at the edge of the peat bog. The waterlogged forest indicated slightly lower values, and a considerably acid environment was identified in the extracted

Tab. 3 – Physical and chemical water properties in observed experimental streams and in groundwater. GWL 1–4 designate aggregate value of all groundwater measurement points within experimental catchment. The stream designates the aggregate value just in the respective experimental stream.

Catchment A	Number of measurements	Mean	Standard deviation
Water temperature (°C) stream	21	10.70	2.25
Dissolved oxygen (mg/l) stream	21	18.80	3.07
Electric conductivity (μS/cm) stream	21	83.76	68.55
Stream water pH	21	5.82	0.76
Water temperature (°C) GWL 1-4	84	11.51	1.88
Dissolved oxygen (mg/l) GWL 1-4	84	16.75	4.12
Electric conductivity (μS/cm) GWL 1-4	84	39.64	8.52
pH 1-4 GWL	84	4.27	0.64
Catchment B	**Number of measurements**	**Mean**	**Standard deviation**
Water temperature (°C) stream	19	17.85	4.54
Dissolved oxygen (mg/l) stream	19	18.91	1.93
Electric conductivity (μS/cm) stream	19	146.47	86.37
Stream water pH	19	3.95	0.41
Water temperature (°C) GWL 1-4	84	14.47	1.91
Dissolved oxygen (mg/l) GWL 1-4	84	16.65	3.36
Electric conductivity (μS/cm) GWL 1-4	84	60.98	17.84
pH 1-4 GWL	84	3.68	0.28
Catchment C	**Number of measurements**	**Mean**	**Standard deviation**
Water temperature (°C) stream	21	10.02	1.79
Dissolved oxygen (mg/l) stream	21	18.92	2.17
Electric conductivity (μS/cm) stream	21	89.43	61.49
Stream water pH	21	4.77	0.79
Water temperature (°C) GWL 1-4	84	11.67	2.09
Dissolved oxygen (mg/l) GWL 1-4	84	18.23	2.83
Electric conductivity (μS/cm) GWL 1-4	84	57.52	19.23
pH 1-4 GWL	84	4.12	0.60

part of the peat bog where there is probably rapid rainout of organic substances, causing a low pH. In addition, there are low values of standard deviations, i.e. the pH is constantly low for the whole measuring period.

The identification of the measure of interdependence between observed parameters was calculated by means of Pearson correlation coefficients that were always assessed separately within particular measurement points. Mutual comparison of all the parameters resulted in a total of 36 correlations.

For a better illustration, the measurement points were added to the table within each catchment where correlation of parameters was identified (Table 4). The measured parameters of GWL and discharge were connected in the category "water quantity". Strong mutual relationships were identified in case of the catchment B, where all measurement points within the catchment showed a correlation between electric conductivity and the amount of dissolved oxygen. Four of five

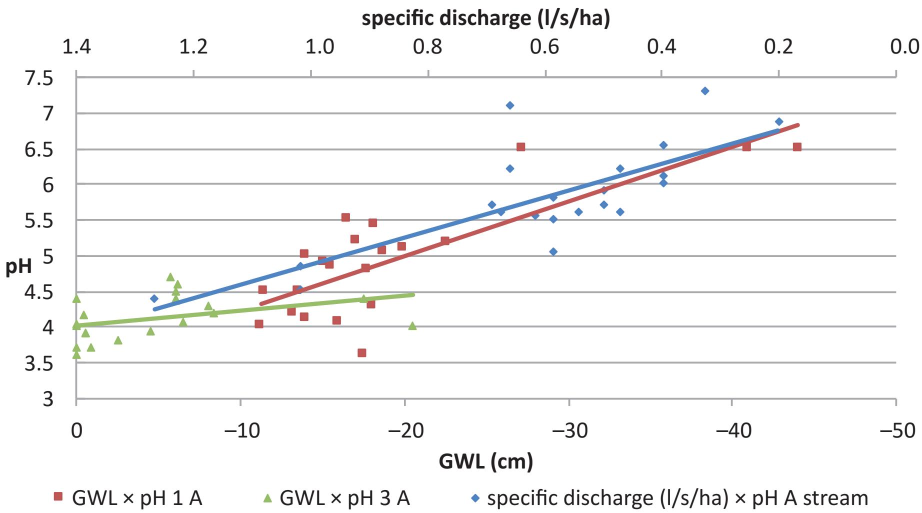
Tab. 4 – Number of correlations of observed parameters at measurement points within experimental catchments

Catchment A	Water quantity	Water temperature (°C)	Dissolved oxygen (mg/l)	Electric conductivity (µS/cm)	pH
Water quantity		1	1		3
Water temperature (°C)	1			1	
Dissolved oxygen (mg/l)	1			1	2
Electric conductivity (µS/cm)		1	1		1
pH	3		2	1	
Catchment B	**Water quantity**	**Water temperature (°C)**	**Dissolved oxygen (mg/l)**	**Electric conductivity (µS/cm)**	**pH**
Water quantity		4	1		
Water temperature (°C)	4			1	1
Dissolved oxygen (mg/l)	1			5	2
Electric conductivity (µS/cm)		1	5		3
pH		1	2	3	
Catchment C	**Water quantity**	**Water temperature (°C)**	**Dissolved oxygen (mg/l)**	**Electric conductivity (µS/cm)**	**pH**
Water quantity		1		1	2
Water temperature (°C)	1		1	1	
Dissolved oxygen (mg/l)		1		1	1
Electric conductivity (µS/cm)	1	1	1		1
pH	2		1	1	

measurement points showed a mutual relationship between the water quantity and its temperature. Moreover, considerable interdependences were evident between the amount of dissolved oxygen and pH and between electric conductivity and pH. On the contrary, the smallest correlation was identified between the water quantity and pH at two measurement points in the area of waterlogged spruce forest. The same correlation was also identified at three measurement points of lagg. There was also perceived a considerable correlation between the pH and the amount of dissolved oxygen.

Figure 9 shows the calculated correlations of particular parameters within the experimental catchments, identified at multiple measurement points. In terms of catchment A, there were three measurement points with correlation between pH and water quantity (specific discharge and GWL) and two measurement points with correlation between pH and the amount of dissolved oxygen. The progress of the linear functions indicates that the pH in the lagg increased with a declining water quantity in the peat and stream. In the case of groundwater, higher peat aeration probably results in an increase of pH. In two cases it was identified that an increase of pH results in an increase of the amount of dissolved oxygen in water.

At the extracted part of the peat bog, a correlation between the GWL and water temperature (Fig. 10) was identified in four cases. It showed that low GWL meant warmer groundwater. This probably relates to the fact that during sunny days, dark and exposed bare peat absorbs a lot of heat, resulting in a rapid decrease of the GWL and an increase of water temperature. Another reason could be the changes in the heat conductivity of peat after its drying. In addition, a connection was proved also between the dissolved oxygen and electric conductivity. An increasing



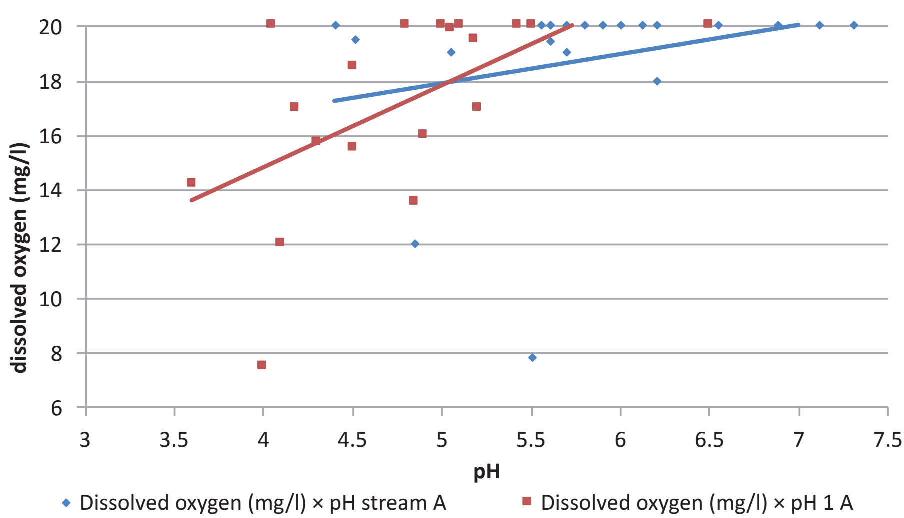
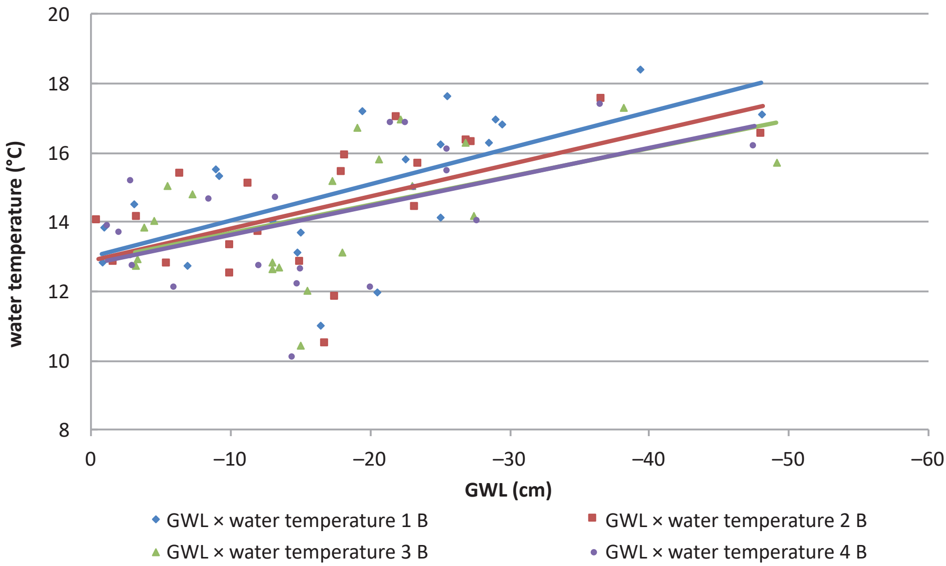


Fig. 9 – Graphic representation of correlations that were identified more than once in experimental catchment A

electric conductivity resulted in this case in higher dissolved oxygen concentration at all measurement points. Just as in the case of the lagg, there is a situation when an increase in pH occurs at lower GWL. Three measurement points were identified where the water pH decreased while the electric conductivity increased.



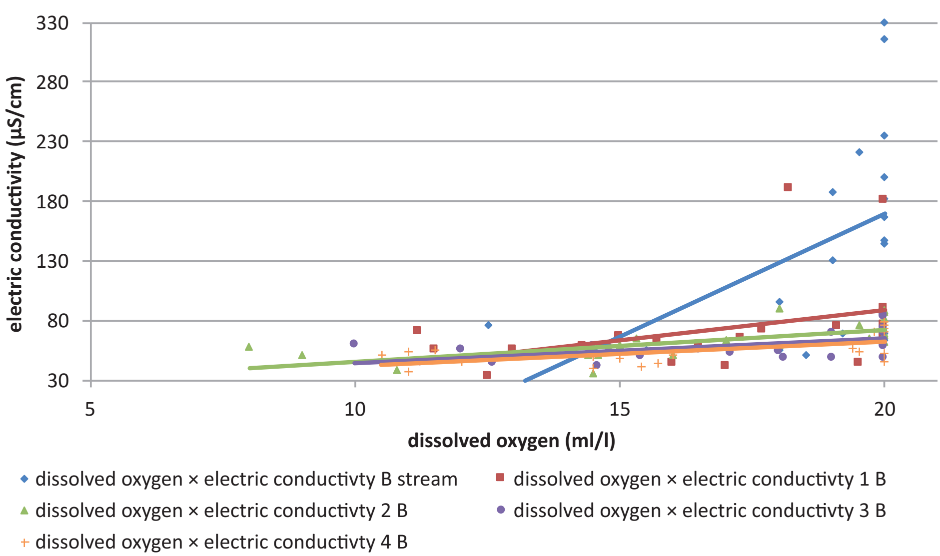
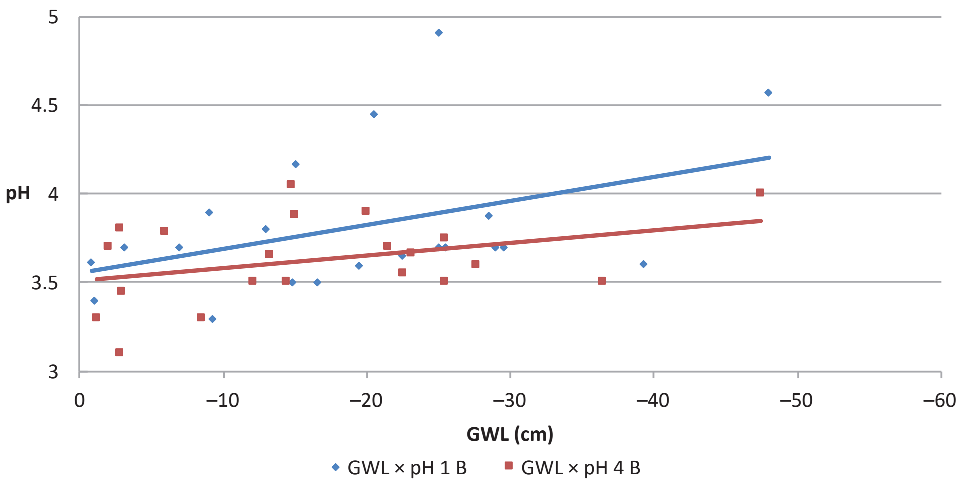


Fig. 10a – Graphic representation of correlations that were identified more than once in experimental catchment B



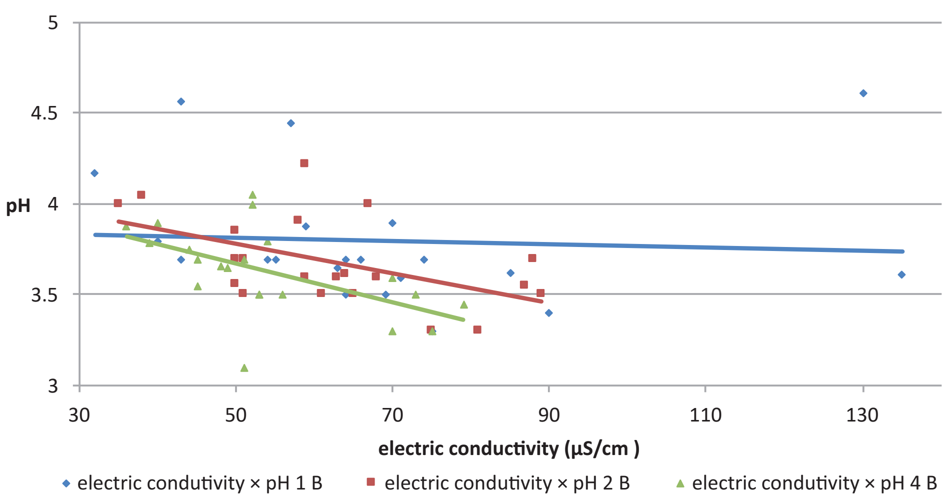


Fig. 10b – Graphic representation of correlations that were identified more than once in experimental catchment B

The catchment in the waterlogged forest showed only one correlation between measured parameters. It was a case of the stream and the nearest GWL point (Fig. 11). As in the previous two experimental catchments, this is the trend when a decreasing quantity of flows or the GWL results in an increase of pH.

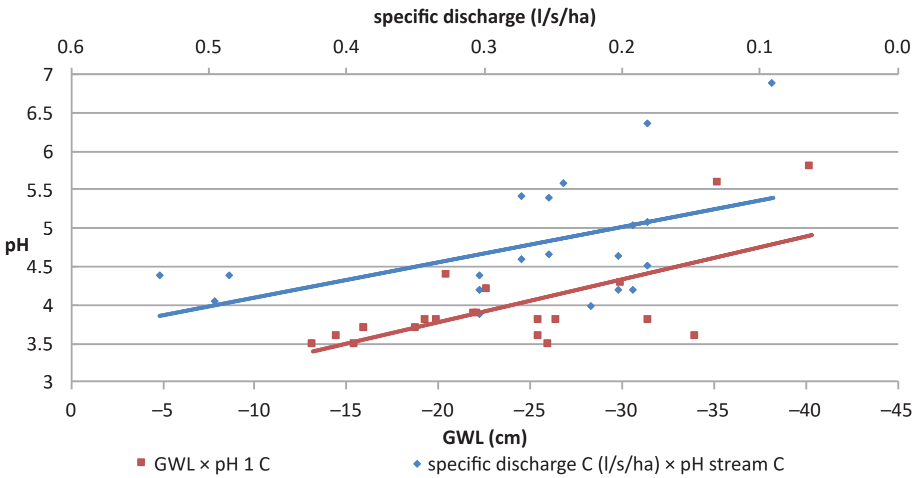


Fig. 11 – Graphic representation of correlations that were identified more than once in experimental catchment C

5. Discussion

The latest studies describing hydrological regime of the headwater area of the Otava river basin indicate that the occurrence of peat bogs in the catchment could be at the origin of higher variability of runoff. This claim was proved by an analysis that showed a very strong dependence of the flow extremity on the proportion of peaty area in the catchment (Čurda, Janský, Kocum 2011). Vlček (2017) also observed that the period of maximum saturation of peat bogs resulted in a rapid rise of runoffs. Furthermore, during the dry periods, the peat bogs store water which means that they do not supply streams. In terms of experimental catchments, it was shown that in observed growing season, the highest variability of the discharges and GWL was identified in the extracted part of the peat bog. The extracted part also reacted negatively during hot summer days when the stream was completely dried up. The most probable cause could be the absence of vegetation. Similar results in anthropogenically disturbed parts of the peat bog were also reported by Holden et al. (2011). In addition, Holden, Chapman, Labadz (2004) point out that even minor changes in the water regime can alter the balance between the decomposition and accumulation of organic matter, which can negatively affect peat bog ecosystems. Statistical characteristics indicated similar progress of the GWL and variability of the discharge in case of lagg and waterlogged forest. Wilson et al. (2011) attribute this behaviour to the buffer effect of vegetation. Trees and shrubs could probably decrease the variability of discharge and also equilibrate a higher and more stable GWL. A similar connection between vegetation cover and the stability and height of the GWL is also described by Labadz et al. (2010) and, in terms of the Šumava Mts., by Bufková, Stíbal (2012) and Kučerová, Kučera, Hájek (2009). In addition, the studies suggest that GWL is especially controlled by the difference between precipitation and evapotranspiration, which was described by Wilson et al. (2011), Allott et al. (2009), and in terms of the Šumava Mts. by Doležal et al. (2017).

The temperature conditions of the surface water and groundwater in observed area are affected by the amount of incoming solar radiation and by the vegetation pattern. High temperatures of water were observed mainly in the extracted part, where there is only bare peat. On the contrary, both the lagg and waterlogged forest showed almost identical temperature conditions. However, Puranen, Mäkilä, Säävuori (1999) point out that temperature variability in acrotelm varies very quickly and considerable differences can be measured within the peat bog. Kučerová, Kučera, Hájek (2009) state that a vegetation effect is identified particularly in the summer during dry seasons when high temperatures result in considerable changes in the albedo and evapotranspiration in the peat bog.

A very low pH was identified in the extracted part of the peat bog. This was also observed in the study by Wind-Mulder, Rochefort, Vitt (1996). A low pH and its higher variability can be explained by a more rapid release of acid organic substances from peat during more intense precipitation events. Lagg showed in this case a relatively high pH. However, Howie, Meerveld (2011) point out that in this regard the lagg can be very variable, as it can be affected by influent mineralized water present in the surroundings of the peat bog. In observed season, the pH values in the groundwater of the waterlogged forest did not differ that much from the pH values of the lagg, but the pH value of the stream was on average lower by almost 1.1. A very strong negative correlation was identified between pH and water quantity in all observed catchments. In a dry period, the water in peat showed higher pH, which can also be attributed to the rainout of organic substances from the peat, which ceases in dry periods. In addition, the similar results in terms of the Šumava Mts. were observed by Prokš (2010).

In this paper, a connection between low pH and higher values of electric conductivity was observed in case of the extracted part. The amount of dissolved substances and the pH can determine the mountain bog pattern and related processes. Similar process was observed in Ponziani et al. (2011). The paper by Wind-Mulder, Rochefort, Vitt (1996) also indicated considerably higher values of electric conductivity in comparison of anthropogenically disturbed parts of peat bog with its intact parts. An interesting finding is that the stream in the waterlogged forest has on average almost identical progress of electric conductivity as the lagg, but it has considerably higher values in terms of groundwater, where they are comparable with the values in the extracted part of the peat bog.

In comparison of the values of dissolved oxygen, it was identified that the three experimental catchments are comparable in this regard. A slightly higher concentration was only identified for the groundwater of the waterlogged forest. O'Driscoll et al. (2016) mentioned a significant temperature effect on the amount of dissolved oxygen. However, these correlations in the case of the experimental catchments were not identified. In terms of dependences, a considerable relationship between dissolved oxygen and electric conductivity was identified, but only in the extracted part of the peat bog. In terms of the lagg, the dependence of dissolved oxygen on pH was identified. However, both of these correlations may be affected by specific physical-geographical factors. For confirmation of these claims, longer data series, which could affect variability of precipitation, is needed. Results were based on experimental measurements in only one growing season and compared to results stated in similar short-term studies of peat bogs. But there are many factors influencing physico-chemical properties of water and hydrological regime. This paper showed differences in progress of observed parameters in various types of peat bog and it was compared to results of related studies. However, all the results from this paper need to be confirmed by long-term measurements.

6. Conclusion

The main objective of this study was to describe differences in behaviour of surface water and groundwater at three peat bog sites with different vegetation covers. Considerable differences were found at the disturbed site. Drainage and peat extraction resulted in low GWL, rapid dynamics of changes in the GWL and discharges. The absence of vegetation in such site indicates a non-standard hydrological regime and its negative effects in comparison with lagg or waterlogged forest. Both of these experimental catchments showed relatively stable discharges and GWL. Another important aim of the study was to describe the basic physico-chemical properties of water in various types of peat bogs. In comparison with intact parts of the peat bog, different water properties were observed in the parts disturbed by extraction. There were considerable declines of the GWL and low specific discharges identified, followed by higher water temperature, unlike in the case of the lagg and waterlogged forest. This aspect contributes to changes in the remaining physical and chemical water properties. In the disturbed part, there were also very low pH values measured. It is probably caused by the absence of vegetation, which allows intensive rainout of organic substances. Moreover, higher values of electric conductivity appeared at the disturbed site. On the contrary, the lagg shows high pH values, which indicate a gradual soil mineralization towards the edge of the peat bog. In terms of other observed parameters, both the lagg and waterlogged forest showed comparable values. The last aspect of the paper was to identify the dependencies of physical and chemical parameters on the quantity of water stored in the catchment. A strong correlation was observed between the water quantity and pH. Precipitation is probably followed by a rapid rainout of organic substances, which caused a decrease in pH at all monitored catchments. In addition, the dependence between a low pH and electric conductivity was identified. This dependence is probably caused by the large amount of free hydrogen anions in the period when the peat bog is suffering from water deficiency. The results of the study are mostly in compliance with the other discussed studies. Nevertheless, this study, based on the observation of a unique vegetation season, could contribute to the general knowledge of these specific sites. In the context of increasing frequency of hydrological extremes, it appears appropriate to continue studying hydrological regime at sites with high retention potential. To understand processes ongoing in various types of peat bogs, continual observation of dynamics of groundwater level and runoff is essential. It is also necessary to focus on those parts of peat bogs that are the most involved in rainfall runoff processes; for this purpose, natural tracers and other modern methods can be used.

References

ALLOTT, T.E.H., EVANS, M.G., LINDSAY, J.B., AGNEW, C.T., FREER, J.E., JONES, A., PARNELL, M. (2009): Water tables in Peak District blanket peatlands. Moors for the future. Edale, Derbyshire.

ANDĚRA, M., ZAVŘEL, P. (2003): Šumava – příroda, historie, život. Baset, Praha.

BERGSMA, B., QUINLAN, C. (2009): Sifton Bog ESA – Conservation Master Plan 2009–2019. Upper Thames River Conservation Authority, Parks, London.

BUFKOVÁ, I., PRACH, K. (2006): Linking vegetation pattern to hydrology and hydrochemistry in a montane river floodplain, the Šumava National Park, Central Europe. Wetlands Ecology and Management, 14, 4, 317–327.

BUFKOVÁ, I., STÍBAL, F. (2012): Restoration of drained mires in the Šumava National Park. In: Jongepierová, I., Pešout, P., Jongepier, J.W., Prach, K. (ed.): Ecological restoration in the Czech Republic, Nature Conservation Agency of the Czech Republic, Prague, 78–80.

ČURDA, J., JANSKÝ, B., KOCUM, J. (2011): Vliv fyzicko-geografických faktorů na extremitu povodní v povodí Vydry. Geografie, 116, 3, 335–353.

DOLEŽAL, T., VLČEK, L., KOCUM, J., JANSKÝ, B. (2017): Evaluation of the influence of mountain peat bogs restoration measures on the water table level: case study Rokytka peat bog, the Šumava Mts., Czech Republic. Acta Universitatis Carolinae. Geographica. Univerzita Karlova, 52, 2, 1–10.

EVANS, M. G., BURT, T. P., HOLDEN, J., ADAMSON, J.K. (1999): Runoff generation and water table variations in blanket peat: evidence from UK data spanning the dry summer of 1995. Journal of Hydrology, 3–4, 221, 141–160.

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, 95–123.

HOLDEN, J., WALLAGE, Z.E., LANE, S.N., MCDONALD, A.T. (2011): Water table dynamics in undisturbed, drained and restored blanket peat. Journal of Hydrology, 1–2, 402, 103–114.

HOJDOVÁ, M., HAIS, M., POKORNÝ, J. (2005): Microclimate of a peat bog and of the forest in different states of damage in the Šumava National Park. Silva Gabreta, 11, 1, 13–24.

HOWIE, S.A., MEERVELD, I.T. (2011): The Essential Role of the Lagg in Raised Bog Function and Restoration: A Review. Wetlands, 31, 3, 613–622.

JANSKÝ, B., KOCUM, J. (2008): Peat bogs influence on runoff process: case study of the Vydra and Křemelná River basins in the Šumava Mountains, southwestern Czechia. Geografie, 113, 4, 383–399.

JOOSTEN, H., CLARKE, D. (2002): Wise use of mires and peatlands – background and principles including a framework for decision-making. International Mire Conservation Group and International Peat Society, Totnes, Devon.

KOCUM, J. (2012): Tvorba odtoku a jeho dynamika v pramenné oblasti Šumavy. Dizertační práce. Univerzita Karlova, Přírodovědecká fakulta, katedra fyzické geografie a geoekologie. Praha.

KŘENOVÁ, Z., HRUŠKA, J. (2012). Proper zonation–an essential tool for the future conservation of the Šumava National Park. European Journal of Environmental Sciences, 2, 1, 62–72.

KUČEROVÁ, A., KUČERA, T., HÁJEK, T. (2009): Mikroklima a kolísání hladiny podzemní vody v centrální části Rokytecké slati. In: Černý, D., Dvořák, L. (eds.): Weitfällerské slatě. Sborník referátů ze semináře 21.1.2009. Správa NP a CHKO Šumava, Vimperk, 50–57.

LABADZ, J., ALLOTT, T., EVANS, M., BUTCHER, D., BILLETT, M., STAINER, S., YALLOP, S., JONES, P., INNERDALE, M., HARMON, N., MAHER, K., BRADBURY, R., MOUNT, D., O'BRIEN, H., HART, R. (2010): Peatland hydrology. Draft scientific review, commissioned by the IUCN UK Peatland Programmes Commission of Inquiry on Peatlands, https://www.iucn-uk-peatlandprogramme.org/resources/commission-inquiry/work-commission-2011/peatland-hydrology (20.9.2019).

LINDSAY, R., BIRNIE, R., CLOUGH, J. (2014): Peat Bog Ecosystems: Structure, Form, State and Condition. IUCN UK Committee Peatland Programme Briefing Note No 2, https://repository.uel.ac.uk/item/85872 (20.9.2019).

O'DRISCOLL, C., O'CONNOR, M., ZAKI-UL-ZAMAN, A., DE EYTO, E., BROWN, L.E., XIAO, L. (2016): Forest clearfelling effects on dissolved oxygen and metabolism in peatland streams. Journal of Environmental Management, 166, 15, 250–259.

PENMAN, H.L. (1948): Natural evaporation from open water, bare soil and grass. Proceedings of the Royal Society of London. Series A, Mathematical and Physical Sciences, 193, 1032, 120–145.

PONZIANI, M., SLOB, E. C., NGAN-TILLARD, D. J. M., VANHALA, H. (2011): Influence of water content on the electric conductivity of peat. International Water Technology Journal, 1, 1, 14–21.

PROKŠ, M. (2010): Odtokový režim v povodí Hamerského potoka se zaměřením na reakci pH vody ve vybraných povodňových epizodách. Diplomová práce. Univerzita Karlova, Přírodovědecká fakulta, katedra fyzické geografie a geoekologie, Praha.

PURANEN, R., MÄKILÄ, M., SÄÄVUORI, H. (1999): Electric conductivity and temperature variations within a raised bog in Finland: Implications for bog development. The Holocene, 9, 1, 13–24.

ŠEFRNA, L. (2004): Pedologická charakteristika povodí Otavy ve vztahu k povodním. Sborník příspěvků GAČR 205/Z052/03, 196–212.

ŠRÁČEK, O., KUCHOVSKÝ, T. (2003): Základy hydrogeologie. Masarykova Univerzita v Brně, Přírodovědecká fakulta.

VLČEK, L. (2017): Retence vody v půdách horských oblastí na příkladu Šumavy. Dizertační práce. Univerzita Karlova, Přírodovědecká fakulta, katedra fyzické geografie a geoekologie, Praha.

VLČEK, L., KOCUM, J., KUČEROVÁ, A., JANSKÝ, B., ŠEFRNA, L. (2012): Retenční potenciál a hydrologická bilance horského vrchoviště: případová studie Rokytecké slatě, povodí horní Otavy, jz Česko. Geografie, 117, 4, 371–395.

WILSON, L., WILSON, J., HOLDEN, J., JOHNSTONE, I., ARMSTRONG, A., MORRIS, M. (2011): The impact of drain blocking on an upland blanket bog during storm and drought events, and the importance of sampling-scale. Journal of Hydrology 404, 3-4, 198–208.

WIND-MULDER, H.L., ROCHEFORT, L., VITT, D.H. (1996): Water and peat chemistry comparisons of natural and post-harvested peatlands across Canada and their relevance to peatland restoration. Ecological Engineering, 7, 3, 161–168.

WORRALL, F., BURT, T., ADAMSON, J. (2006): Long-term changes in hydrological pathways in an upland peat catchment—recovery from severe drought? Journal of Hydrology, 321, 1, 5–20.

ORCID

TOMÁŠ DOLEŽAL
https://orcid.org/0000-0002-6074-8294

LUKÁŠ VLČEK
https://orcid.org/0000-0002-6906-6054

JAN KOCUM
https://orcid.org/0000-0001-7698-8033

BOHUMÍR JANSKÝ
https://orcid.org/0000-0002-2547-307X