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Research paper

Possible impacts of floods and droughts on water quality

Tomáš Hrdinka [a,*], Oldřich Novický [a], Eduard Hanslík [b], Mark Rieder [c]

[a] T.G. Masaryk Water Research Institute, Department of Hydrology, Podbabská 2582/30, CZ 160 00 Prague 6, Czech Republic
[b] T.G. Masaryk Water Research Institute, Department of Radioecology, Podbabská 2582/30, CZ 160 00 Prague 6, Czech Republic
[c] T.G. Masaryk Water Research Institute, Podbabská 2582/30, CZ 160 00 Prague 6, Czech Republic

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Abstract

The gradual climate change symptoms in many places on Earth have been observed during the last 20 years. There is a significant increase in frequency and extremity of meteorological and hydrological events (EEA, 2007) that lead to distinct excess or lack of water in landscape. These phenomena affect not only actual quantity of water but also its quality with direct and indirect impacts on aquatic organisms. From the environmental impact point of view, drought events are considered to be more dangerous due to their medium-term to long-term characteristics and large spatial impacts. However, this study presents that the particular flood event had significantly greater impact on water quality than the period of drought even if for only a very short time The paper reviews changes in water quality with all its consequences during selected extreme hydrological situations in the Czech Republic in last 10 years and compares them with the knowledge of impacts of floods and droughts on water quality collected from literature.

Keywords: Flood; Drought; Water quality; Czech Republic

1. Introduction

In the last 15 years, the Czech Republic has been affected by three extreme floods with return period exceeding frequently 100 years (locally even 500–1000 years). The 1997 and 2002 floods were caused by long-term regional rainfalls that affected substantial part of the country. The spring 2006 flood (at the end of March) was less extensive in its devastating effect, despite greater return periods than the 2002 flood at several water gauging stations. Particularly the southern part of Bohemia and Moravia was highly affected by intensive precipitation strengthened by a quick snow cover melting in the lowland areas. The severe heat wave, which began in Europe in June 2003 and continued through July until mid-August, was reflected in raising summer temperatures by 20–30% as compared to the seasonal average over a large portion of Europe. Consequent drought in 2003 caused vast environmental damages in the European countries particularly in southern and Western Europe. This drought also affected almost the whole area of the Czech Republic with exception of several mountain regions.

Increasing frequency and severity of the hydrological extreme events is mostly attributed to impacts of already ongoing climate change. This was discussed in great number of literature sources, including those focused on conditions in the Czech Republic, such as Kašpárek et al. (2006b), (2008), Novický et al. (2005), (2009a) and (2010).

2. Data and methods

On March 28, 2006, 35 mm of rainfall was recorded over some areas of the Czech Republic (Fig. 1a). The rainfall together with 50 cm mean snow cover (Fig. 1b) and several preceding days with maximum temperature over 20 °C led to intensive floods (VRB, 2006; Kašpárek et al., 2006a). Impacts

* Corresponding author. Tel.: +420 220 197 337.
E-mail addresses: tomas_hrdinka@vuv.cz (T. Hrdinka), oldrich_novicky@vuv.cz (O. Novický), eduard_hanslik@vuv.cz (E. Hanslík), mark_rieder@vuv.cz (M. Rieder).

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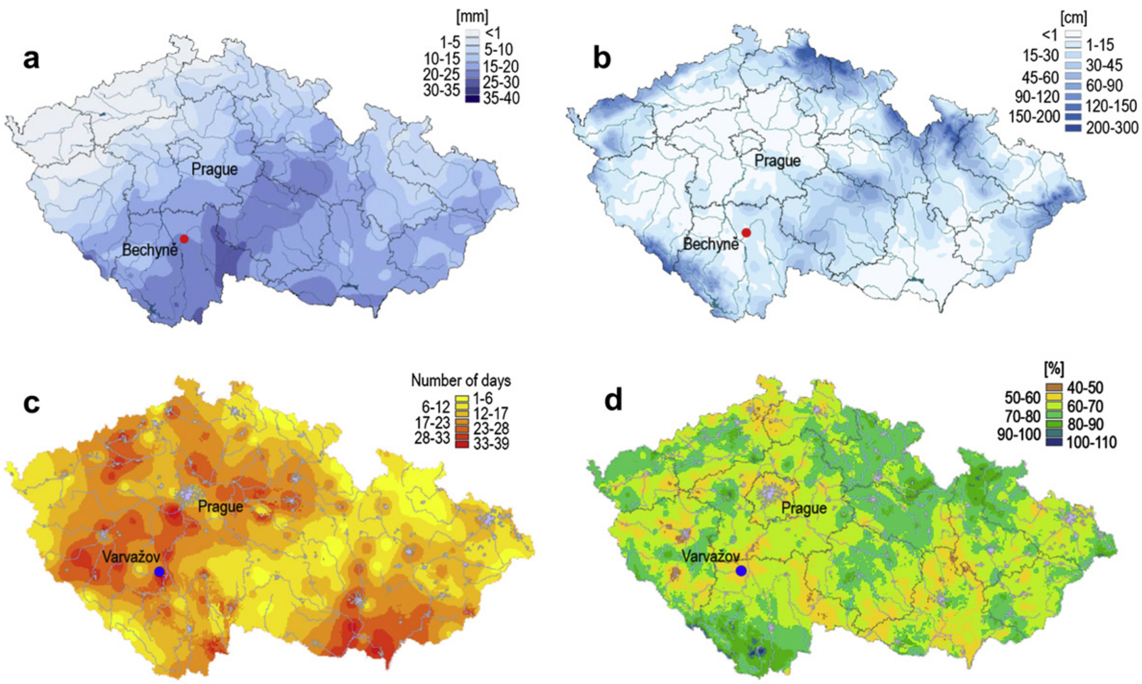

Fig. 1. Weather patterns over the Czech Republic prior to the 2006 (a,b) and 2003 (c,d) extreme hydrological events – a) daily precipitation on March 28, 2006; b) snow cover on March 27, 2006; c) tropical days from Jan 1, 2003 to Aug 19, 2003; d) precipitation from Jan 1, 2003 to Aug 20, 2003 related to the 1961–90 average.

of the flood on water quality were assessed by using data from the Lužnice River basin (Table 1), which was highly affected. At Bechyně water gauging station, located close to the mouth of the Lužnice River, which is a tributary of the Vltava River, the return period of the peak discharge reached almost 50 years.

In the period from June to September 2003, the Czech Republic experienced only 60% of the normal precipitation (Fig. 1d) and river flows in most of Czech streams consequently fluctuated between 15% and 65% of the long-term means (Řičicová et al., 2004; CHMI, 2004). The mean temperature in this period exceeded that from the reference period (1961–1990) by 2.5 °C and an extreme occurred particularly in a number of tropical days (Fig. 1c). The drought impact analysis was carried out for the Skalice River (Table 1)

Table 1
Principal characteristics of the Lužnice River and the Skalice River basins.

Lužnice River at Bechyně sampling station		Skalice River at Varvažov sampling station	
Source elevation	970 m a.m.s.l.	Source elevation	678 m a.m.s.l.
Supe elevation	615.9 m	Super elevation	297.5 m
Length of river	197.4 km	Length of river	48.7 km
Slope of river	3.1 ‰	Slope of river	6.1 ‰
Catchment area	4055.13 km^2	Catchment area	368.53 km^2
Annual discharge Q_a	23.6 m^3	Annual discharge Q_a	1.51 m^3
Flood discharge Q_1	111 m^3	Drought discharge Q_{330}	0.182 m^3
Flood discharge Q_{50}	488 m^3	Drought discharge Q_{355}	0.087 m^3
Flood discharge Q_{100}	577 m^3	Drought discharge Q_{364}	0.032 m^3

in central Bohemia, whose discharges dropped to 5%–20% of the long-term monthly means. The data for the analysis were available for Varvažov water gauging station, which is located close to the confluence of the Lomnice and Vltava Rivers.

It is a rather difficult problem to collect data for the analysis of water quality during a flood because most hydrological activities during a flood are commonly focused on evaluation of the flows. For the 2006 flood, the water quality data were available from regular monitoring conducted with monthly frequency and from several short-term monitoring programmes performed during the flood (selected indicators only). For the purposes of the study, the water quality data from approximately one month before and after the flood were used as reference conditions. The conditions during the flood were represented by water samples taken at the beginning of the flood (March 28, 2006), and two and seven days after the occurrence of the flood peak. The values of water quality shown in Fig. 2 represent in situ measurements (water temperature, dissolved oxygen content) and the results of laboratory analyses (biological and chemical oxygen demand, metals, suspended and dissolved solids, specific organic compounds, microbiology). The data were provided by Vltava River Basin state enterprise and Czech Hydro-meteorological Institute.

To assess the drought impact, the water quality data from the 2003 drought (June to September) were compared with those from two previous and two following years. The values of the water quality characteristics shown in Fig. 3 were calculated as arithmetic averages of the results from point water sample analyses made in the individual years in the periods from June to September. The water samples were taken annually approximately in identical days. This method

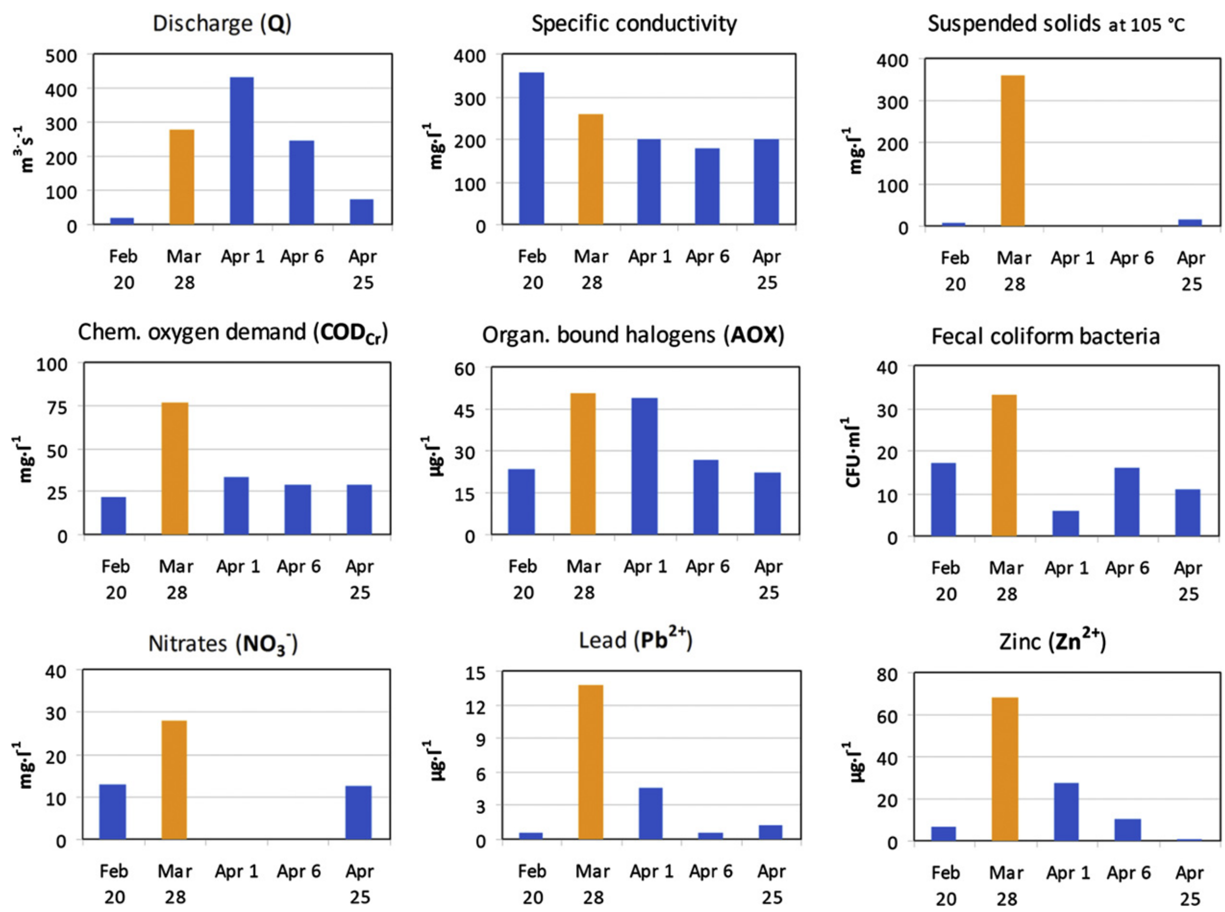

Fig. 2. Selected water characteristics of the Lužnice River at Bechyně during the 2006 flood compared to the pre- and post-flood reference conditions (the first and the last column).

was also used for calculation of the river water flows by using data from the Varvažov water gauging station. The results of the sampling and analysis were checked for not being influenced by casual local conditions, e.g. rainstorm, waste water treatment plant emission etc. Due to four months' duration of the 2003 drought, the resulted mean values are considered as sufficiently relevant to illustrate stable conditions at the sampling site in the selected time period in the years 2001–2005. The data were provided by the Czech Hydrometeorological Institute.

The values measured at Varvažov and Bechyně sites were subsequently compared with relevant data from other flood and drought events in the Czech Republic and Europe and with the limits for assessing surface water quality in the Czech Republic specified in Czech National Standard No. 75 7221 (CSNI, 1998) (Table 2). Potential impacts of floods and droughts on water organisms were reviewed by using information from literature, the observed changes in physical and chemical water characteristics and knowledge concerning erosion and sedimentation processes.

3. Results and discussion

The extremity of the analysed flood can be illustrated by its peak discharge (the Lužnice River at Bechyně) of 481.3 $m^3 \cdot s^{-1}$ on March 30 (15 times greater as compared to that 5 days before), whose return period was about 50 years (Table 1). The four month drought discharge of the Skalice River at Varvažov was 0.112 $m^3 \cdot s^{-1}$, which is only 9% of that in the reference period 2001–02 and 27% of that in 2004–05. In August 2003 the discharge dropped to 0.049 $m^3 \cdot s^{-1}$ corresponding to Q_{364}–Q_{355} (Table 1). The results illustrating changes in selected physical and chemical characteristics of water in the Lužnice and Skalice Rivers under the extreme hydrological conditions are given in Figs. 2 and 3.

Surface water temperature, which affects many other qualitative water parameters, has gradually been increasing during the last two decades (Novický et al., 2009b; Hammond and Pryce, 2007) as a consequence of climate change. Significant increase was recorded during the drought period in 2003, when the water temperature of the Skalice River at Varvažov exceeded that in the 2001–05 reference period by 1.7 °C, similarly to approximately 2 °C increase at the two sites on the Meuse River in the same year (van Fliet and Zwolsman, 2008). In addition to the natural conditions, considerable changes in water temperature could originate from anthropogenic impacts, particularly from reservoir operations and industry (Laws, 2000). In this sense there is no significant source of point thermal pollution presented in both catchments.

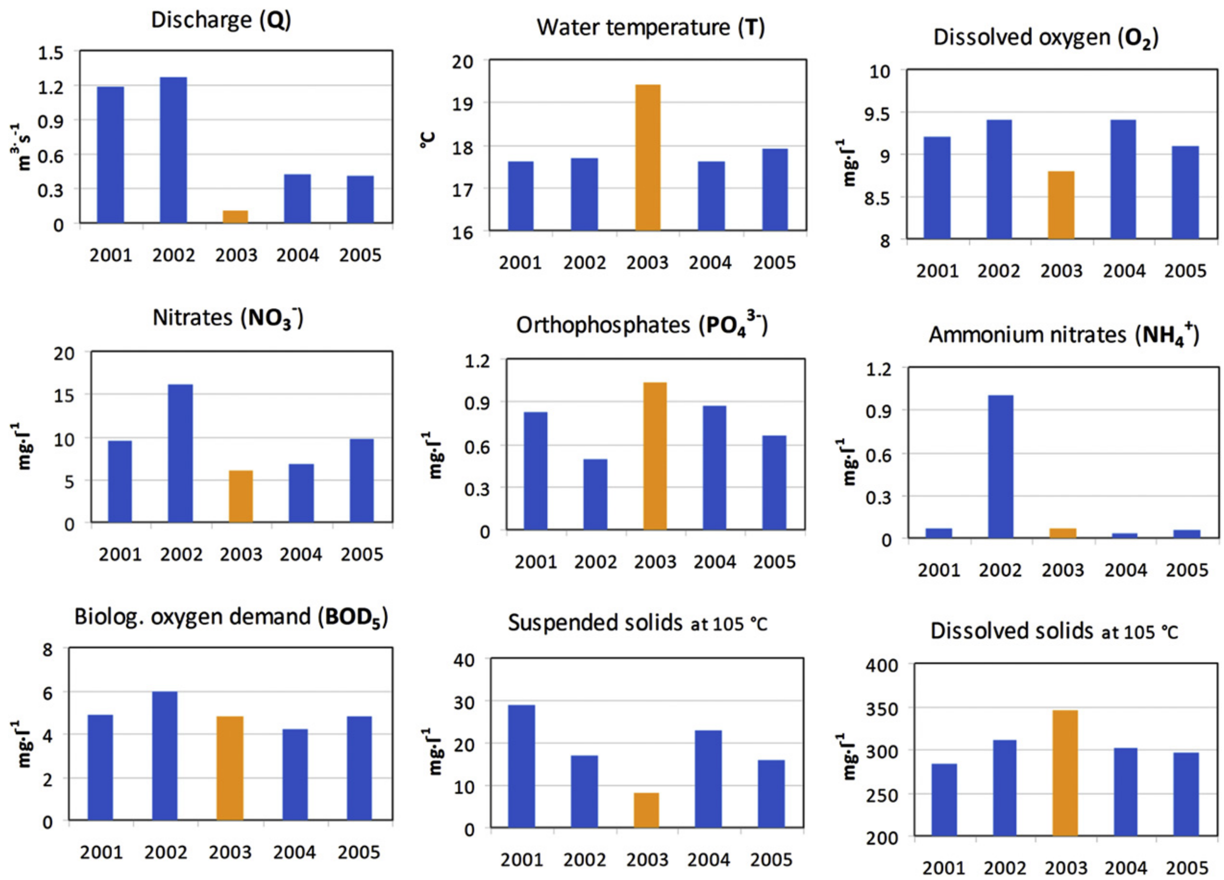

Fig. 3. Selected water characteristics of the Skalice River at Varvažov during the 2003 drought compared to those in the reference periods 2001–02 and 2004–05.

Water warming and high pollution with organic substances from communal sources were reported (van Fliet and Zwolsman, 2008; Prathumratana et al., 2008) to be the main causal factors of a decrease in oxygen concentrations in water during drought periods (especially in lentic environment). This conclusion was not substantiated for the Skalice River. This is illustrated in Fig. 3, which shows that the oxygen concentration decreased by 5% only against the reference period with minimum oxygen saturation 81% in August 2003. This is probably attributable to very good reaeration processes due to stony bed of the 10 km long river section above the sampling site with outcrops of the Central Bohemian Pluton at approximately 50% of its length. Because of the fact that no changes in chlorophyll-*a* concentrations were recorded, the oxygen decrease is mainly related to the higher water temperature. On the other hand, accelerated changes in phyto- and zooplankton growth cause variations in oxygen distribution and enhance oxygen gradients in surface-bottom direction (Williams et al., 2000). There is a possibility of anoxic conditions in lentic habitats during drought periods with all negative consequences for aquatic organisms (Conlan et al., 2007). Floods usually improve oxygen concentrations in rivers due to high flow velocities, although, in highly polluted urban or agricultural areas the storm runoff with high

Table 2
Surface water quality classes according to the Czech National Standard No. 75 7221.

Parameter	Unit	Class					Parameter	Unit	Class				
		1	2	3	4	5			1	2	3	4	5
Spec. conductivity	μS cm^{-1}	<400	<700	<1100	<1600	>1600	PAU total	ng l^{-1}	<10	<100	<500	<3000	>3000
Suspended solids	mg l^{-1}	<20	<40	<60	<100	>100	AOX	μg l^{-1}	<10	<20	<30	<40	>40
Dissolved oxygen	mg l^{-1}	>7.5	>6.5	>5	>3	<3	Chromium	μg l^{-1}	<5	<20	<50	<100	>100
BOD_5	mg l^{-1}	<2	<4	<8	<15	>15	Zinc	μg l^{-1}	<15	<50	<100	<200	>200
COD_{Cr}	mg l^{-1}	<15	<25	<45	<60	>60	Copper	μg l^{-1}	<5	<20	<50	<100	>100
TOC	mg l^{-1}	<7	<10	<16	<20	>20	Cadmium	μg l^{-1}	<0.1	<0.5	<1	<2	>2
$N-NH_4^+$	mg l^{-1}	<0.3	<0.7	<2	<4	>4	Lead	μg l^{-1}	<3	<8	<15	<30	>30
$N-NH_3^-$	mg l^{-1}	<3	<6	<10	<13	>13	Arsenic	μg l^{-1}	<1	<10	<20	<50	>50
P total	mg l^{-1}	<0.05	<0.15	<0.4	<1	>1	Fecal bacteria	CFU ml^{-1}	<40	<100	<500	<1000	>1000
PCB total	mg l^{-1}	<5	<10	<20	<30	>30	Enterococci	CFU ml^{-1}	<6	<13	<25	<46	>46

concentrations of organic compounds can lead to quick oxygen depletion in streams and reservoirs with fatal impacts on aquatic organisms (Magaud et al., 1997).

The results of the study mostly substantiated conclusions made by van Fliet and Zwolsman (2008), who reported that concentrations of suspended and dissolved solids are related to river flows. Specific concentrations of suspended solids in the Lužnice River at Bechyně rose up almost 30 times at the beginning of the flood (class 5 according to surface water quality classes specified in the Czech National Standard No. 75 7221, Table 2), whilst 62% decrease was observed for the Skalice River at Varvažov due to low water velocities and long residence time. The river bed sediments are washed away during floods with both positive and negative consequences. This depends primarily on sediment character, e.g. pollutant contamination and concentrations of organic matter that can be locally crucial for water organisms that are fed with bottom detritus. Great input of flood sediments with fixed mineral nutrients (PO_4^{3-}) can cause potential eutrophication of affected water bodies (George et al., 2007). Transport of suspended particles also reduces water utilisation possibilities (drinking water, trickling irrigation, cooling medium in power plants etc.).

The results of the study also showed that concentrations of dissolved solids gradually decreased in the Lužnice River at Bechyně (expressed by specific conductivity) due to dilution as the flood progressed whilst their concentrations in the Skalice River at Varvažov increased by about 16%. These results indicate that the concentrations of dissolved solids per volume unit are lower during floods but the total discharged quantity is normally higher. Similarly to the conclusions made for suspended solids, this can lead to their accumulation in water reservoirs (George et al., 2007). Increased concentrations of PO_4^{3-} ions (by 45%) during the drought period are in harmony with conclusions made by Whitehead et al. (2009), who reported that water resources face up to increased evaporation and point pollution during droughts in urban areas. However, expected higher concentrations of NH_4^+ ions were not observed and similarly to Whitehead et al. (2009) did not record any significant trend. The river is characterised by long-term low, close to threshold limit concentrations of NH_4^+ ions with exception of the year 2002 when the flood occurred. In harmony with the results of observations made by van Fliet and Zwolsman (2008), concentrations of nitrates substantially increased (by 121%) during the flood flows (from class 1 to class 3 according to the Czech Standard) and highly decreased during the low flows (57% as compared to the reference period), which is attributable to changes in surface runoff and consequent washouts from areal and diffuse sources of pollution.

Concentrations of specific organic compounds substantially increased during the first days of the 2006 flood, mainly organically bound halogens (121%, max. 50.4 μg l^{-1}) and polycyclic aromatic compounds (1410%, max. 360 ng l^{-1}). The emissions of these persistent compounds that accumulate in organisms and sediments are under a strict control in the Czech Republic. Their high concentrations are therefore normally detected consequently to industrial accidents and floods, when contaminated areas are washed out by the flood flows. This was also the case of the 1997 and 2002 floods, which washed organic-chlorine pesticides and oil derivates contamination from industrial plants located on the banks of the Morava and Elbe Rivers (Hladný et al., 1998, 2004). The washouts polluted the river downstream and led to flatfish and mussels contamination in the Wadden Sea (Einsporn et al., 2005). The concentrations of dissolved organic compounds in water during the 2006 flood were reflected in increased biological (up to 11.3 mg l^{-1}) and chemical (up to 76.4 mg l^{-1}) oxygen demand, which was more than twice of that during the 2003 drought and corresponding to water quality classes 4 and 5 according to the Czech Standard (Table 2).

Similar conclusions can be made also for concentrations of toxic metals in water and sediments, which are affected by human activities and impacts of point sources of pollution (Paul and Meyer, 2001; Clark et al., 2007). Several metallic ions with high affinity (lead, chromium, mercury) are well bounded with inorganic particles such as suspended solids or river bed sediments (Pitter, 2009) and their concentrations therefore usually rise during floods. This was substantiated by the results of the water quality monitoring during the 2006 flood, when significant increase was detected in zinc (1760%, max. 68 μg l^{-1}), lead (1510%, max. 13.7 μg l^{-1}), chromium (1400%, max. 10.5 μg l^{-1}) and arsenic (900%, max. 5 μg l^{-1}) concentrations. Medium increase was also detected in the concentrations of cadmium (375%, max. 0.38 μg l^{-1}) and copper (279%, max. 9.1 μg l^{-1}). Despite the relatively high increases the maximum observed values correspond mainly with water quality class 2. In harmony with these results, the concentrations of all metallic ions during the 2003 drought were very low and no obvious changes were detected.

Extreme hydrological conditions affect also microbiological indicators of water quality. Dry conditions usually intensify impacts of pollution originating from point sources, particularly concentrations of coliform bacteria and enteroccoci stemming from communal waste water outflows, while microbiological pollution from areal sources is usually caused by intensive washouts from agricultural and cattle breeding areas (Baudišová, 1997). The fact that the 2003 drought had no significant impact on microbiological pollution might indicate, together with very low concentrations of NH_4^+ ions, that the efficiency of local waste water treatment plants was very good although there are no data to verify this assumption. During the 2006 flood, the concentrations of fecal bacteria and enteroccoci temporarily increased by about 140%, but did not exceed water quality class 3. In case of the 2002 flood, the surface water was affected more seriously for longer period of time as a consequence of the fact that the flood damaged 30% of the main waste water treatment plants in the Czech Republic (Hladný et al., 2004).

4. Conclusions

Impacts of the 2006 flood (return period of 50 years) and the 2003 drought (discharge equivalent to Q_{364}–Q_{355}) on water quality were examined at Bechyně (Lužnice River) and

Varvažov (Skalice River) stations in central Bohemia. Both extreme events significantly affected the water quality in comparison with the reference conditions. The low flows were reflected in high increase in water temperature (by 1.7 °C), minor decrease in the concentration of dissolved oxygen, restrained dilution effect and increased concentrations of dissolved solids (by 16%) and phosphates (by 45%). In contrast, concentrations of ammonium ions and bacterial pollution remained surprisingly unchanged probably due to long-term low, close to limit concentrations and assumed good efficiency of local waste water treatment plants. Low water flow velocities contributed to low concentrations of suspended solids (62% decrease) and metals. In terms of surface water quality classification according to the Czech National Standard No. 75 7221, the observed values during the drought period correspond mainly to water quality class 1 and 2 with exception of PO_4^{3-} ions that dropped from class 4 to class 5. During the flood, substantial increase was detected in concentrations of metals (upto 1760%), specific organic compounds (up to 1410%), fecal coliform bacteria (by 136%) and nitrates (by 121%). These high concentrations are attributable mainly to extreme concentrations of suspended solids originating predominantly from vast alluvial washouts. The river pollution was consequently reflected in increased biological (max. 11.3 mg l^{-1}) and chemical (max. 76.4 mg l^{-1}) oxygen demand. The maximum observed values correspond mainly to water quality class 2 or 3, but in some parameters (BOD_5, COD_{Cr}, AOX and suspended solids) the water quality deteriorated to class 4 or class 5. Summarising the data, this particular flood event had significantly greater impact on water quality than the period of drought even if for only a very short time. In order to formulate more general conclusions a comparative study of more catchments within their local specific characteristics is needed.

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