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Possible impacts of climate change on water quality in streams of the Czech Republic

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Abstract The impacts of changes in water temperature and flow on selected water quality parameters, as one of the consequences of climate change, were studied in river catchments in the Czech Republic with little anthropogenic influence. The impact of climate change was manifested by an increase in stream temperature by 1.15°C over 28 years. The selected water quality parameters were dependent on flow, with up to 10-fold increases in the concentrations of ammonia, phosphorus and chlorophyll-*a* at minimum flow levels. In river catchments with point source pollution predominating, significant pollution with ammonia nitrogen was observed. The influence of increased water temperature compared to flow rates was generally less marked and, with the exception of chlorophyll-*a*, rather positive. For existing land management and utilization of these river catchments, extreme changes in flow rates will influence the water quality more substantially than the water temperature itself.

Key words ammonium nitrogen; climate change; Czech Republic; drought; phosphorus; water quality; water temperature

Les impacts possibles du changement climatique sur la qualité de l'eau dans les rivières de République tchèque

Résumé Les impacts des modifications du débit et de la température de l'eau induites par le changement climatique sur un certain nombre de variables de qualité de l'eau ont été étudiés sur des bassins versants de la République tchèque peu soumis à l'influence anthropique. Le changement climatique s'est manifesté par une augmentation de la température de l'eau de 1,15°C en 28 ans. Les variables de qualité de l'eau sélectionnés se sont révélées dépendantes de l'écoulement, avec une augmentation d'un facteur 10 des concentrations en ammoniaque, phosphore et chlorophylle-a à l'étiage. Dans les bassins versants où la pollution ponctuelle prédomine, on a observé une pollution significative par l'azote ammoniacal. Comparée à celle des débits, l'influence de l'augmentation de la température de l'eau est généralement moins prononcée et, à l'exception de la chlorophylle-a, plutôt positive. Pour la gestion des terres et l'utilisation des bassins versants, des changements extrêmes de débits influenceront davantage la qualité de l'eau que la température de l'eau.

Mots clefs azote d'ammoniacal ; changement climatique ; République tchèque ; sécheresse ; phosphore ; qualité de l'eau ; température de l'eau

1 INTRODUCTION

Over the last 20 years, a significant increase in the frequency and extremity of meteorological and hydrological phenomena has been observed in Europe (EEA 2007). Several studies (Middelkoop *et al.* 2001, Kysely 2002, Christensen and Christensen 2007, Hanel *et al.* 2010) have focused on trying to predict the development of water temperature and precipitation in connection with climate change in central Europe. The long-term increase in air temperature together with increasing variability of the climate is reflected in changes in the temperature and flow regime of surface waters (Mimikou *et al.* 2000, Hammond and Pryce 2007, Kašpárek *et al.* 2008, Novický *et al.* 2009, Hanel *et al.* 2012). Novický *et al.* (2009) expect an average increase in water temperature of 1.5–3°C for most streams in the Czech Republic by the year 2050 against the reference year 1975. From the view of the structure and function of surface water ecosystems, temperature is an important factor, but only one of the key factors, of water quality. The relationship of water quality to climate change should be an important focus of studies engaged in determining the effects of climate change. Gradual increases in water temperature together with higher frequencies of dry periods, accompanied by minimum flows, may cause the intermediate- to long-term deterioration of water quality in some streams, connected with an excessive growth of phytoplankton (Desortová and Punčochář 2011), a decrease in dissolved oxygen and a decline in the diversity of aquatic organisms.

The influence of temperature and extreme flows on selected parameters of water quality has been the subject of several studies, e.g. Mimikou *et al.* (2000), Zwolsman and van Bokhoven (2007), Prathumratana *et al*. (2008), van Vliet and Zwolsman 2008 and Pekárková *et al.* (2009). These studies focused on the impacts of particular time-limited periods of droughts, or the application of models for predicting individual parameters. An aggregate study of the possible influence of climate change on surface water quality was published by Whitehead *et al.* (2009). Here, we evaluate both the influence of water temperature and flow on selected parameters of water quality for selected rivers of intermediate size (hundreds of km^2) in the Czech Republic ($N\text{-}NO_3^-$, $N\text{-}NH_4^+$, $P\text{-}PO_4^{3-}$, P_{total}, BOD_5, chlorophyll-*a*), with an emphasis on extreme states. In addition, we provide an assessment and interpretation of long-term trends for the influence of temperature and low flow rates on water quality in conjunction with the specific properties of individual river catchments. This will extend the knowledge usable for assessment of possible impacts of climate change on water ecosystems, in relation to the requirements of the EU Water Framework Directive (WFD 2000).

2 DATA AND METHODS

2.1 Selection of river catchments

This comparative study was carried out based on results from 10 selected model river catchments, taking into account the general geographical-hydrological conditions of the Czech Republic and containing areas with both point and nonpoint source pollution from inorganic forms of nitrogen and phosphorus (Fig. 1 and Table 1). Paticular attention was given to river catchments that have limited influence from excessive anthropogenic water discharge or water intake. Profiles influenced by the manipulation of water reservoirs, pond systems, artificial water transfers and immediate outflows from municipal wastewater treatment plants (WWTP) that markedly interfere with the thermal and nutrient regime of the water environment (Laws 2000) were excluded. In the first phase, 20 river catchments with relatively little anthropogenic influence were selected. These were then screened for completeness and homogeneity of selected water-quality data measured by the Czech Hydrometeorological Institute (CHMI) since 1963.

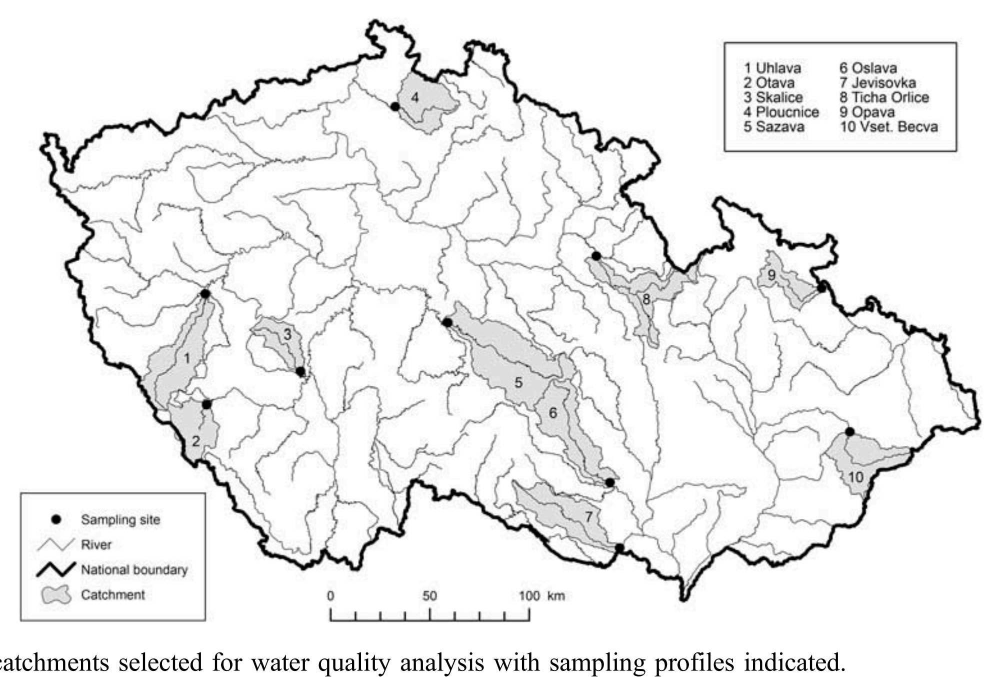

Fig. 1 River catchments selected for water quality analysis with sampling profiles indicated.

Table 1 Selected characteristics of the river catchments according to the land cover, structure of surrounding communities and sources of pollution (catchments in descending order according to the relative area of arable land).

Catchment	Area (km^2)	Arable land (%)	Forest (%)	Grass-land (%)	Population[1]	Population[2]	WWTP[3] (%)	WWTP[4] (%)	Index[5] α	Index[6] β_N	Index[6] β_P
Jevisovka	787.05	67.8	25.0	3.5	32 239	16 933	80.1	42.1	0.941	5281	1187
Skalice	374.94	57.5	24.4	13.9	18 144	12 242	70.2	47.4	0.968	3906	652
Sazava	1508.05	55.4	28.7	11.7	129 036	93 300	72.1	52.2	0.984	4066	1136
Oslava	867.03	52.7	32.0	10.5	58 505	37 723	88.9	57.3	0.952	3679	923
Uhlava	915.13	41.3	33.5	21.7	63 446	51 967	81.2	66.5	0.977	2318	298
Ticha Orlice	757.89	35.4	38.7	19.6	91 187	60 517	87.8	58.3	0.968	2177	428
Ploucnice	627.02	14.0	46.5	31.5	45 957	37 675	62.5	51.2	0.946	580	64
Opava	369.68	6.2	69.5	20.5	12 228	7 792	71.0	45.3	0.974	199	41
Vset. Becva	734.19	3.9	62.1	29.4	72 085	51 760	90.8	65.2	0.938	188	64
Otava	540.63	2.2	75.0	21.9	4 958	3 339	73.2	49.3	0.967	109	13

Notes: [1]total number of inhabitants, [2]number of inhabitants in communities with wastewater treatment plants (WWTP), [3]proportion of inhabitants in communities with WWTP connected to WWTP, [4]proportion of total number of inhabitants connected to WWTP, [5]median of monthly values for the period 1997–2008, [6]average of annual values for the period 1996–2000.

In most cases, profiles where water quality was evaluated did not correspond with the profiles where flow was measured, so average daily flows for sampling profiles were calculated using analogues. In some profiles, these analogues differed by up to 70%, particularly when significant tributaries were not measured at all by the corresponding gauging station. Thus, flow rates in these sampling profiles were derived empirically, with appropriate uncertainty. For the purposes of this study, only those analogues with a value ±10% of the long-term flow (Qa), at the corresponding gauging station were considered.

In Table 1, selected characteristics of land cover, structure of surrounding communities and waste water treatment facilities within the studied river catchments are shown, together with indices of point and nonpoint source pollution levels. The data on land cover were obtained from the CORINE Land Cover 2000 database, and the available data on the fertilizers used on agricultural land for the period 1996–2000 were provided by the Czech Statistical Office (unpublished data). The data on the structure of surrounding communities and waste water treatment facilities for 2009 were obtained from the HEIS database of the T.G. Masaryk Water Research Institute, Prague.

2.2 Data processing

The basic data on water quality were obtained from monthly single-shot measurements taken by the CHMI. Because various analytical methods were used prior to 1990, only data from 1990 and later were analysed. The available data series were 1990–2008 ($N\text{-}NO_3^-$, $N\text{-}NH_4^+$, P_{total}, BOD_5), 1994–2008 ($P\text{-}PO_4^{3-}$) and 1997–2008 (chlorophyll-*a*). The parameter $N\text{-}NH_4^+$ was evaluated only for the period 1997–2008, since the analytical method changed in 1997. Average daily flows were available from 1990 to 2008. During floods, however, the immediate (at sampling) and average daily flows may differ significantly; therefore, a comparison of average daily and hourly flows (available for the period 2004–2008) was performed. In the selected Úhlava River model catchment, where possible changes in flow should be clearly visible, differences between the hourly and daily average flows were marginal and without distinct effects on the trend characteristics of the evaluated variables (Fig. 2(a)). The long-term development of water temperature was evaluated using annual averages from the period 1960–2006 (Fig. 3), calculated from daily average water temperature values at the

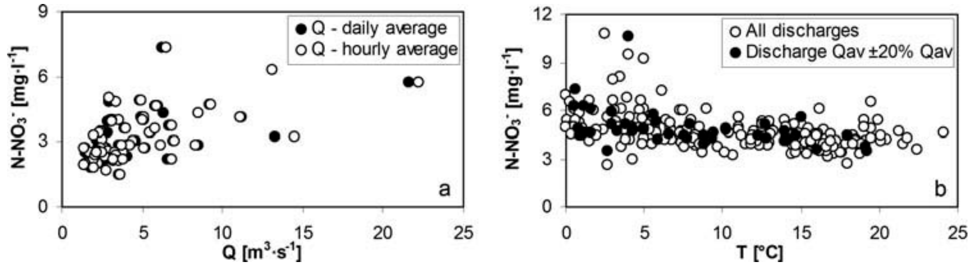

Fig. 2 (a) Comparison of deviations in the daily average and hourly average discharge in the Úhlava River catchment for the period 2004–2008, and (b) comparison of analyses for all runoff situations and those without extreme flows in the Tichá Orlice River catchment.

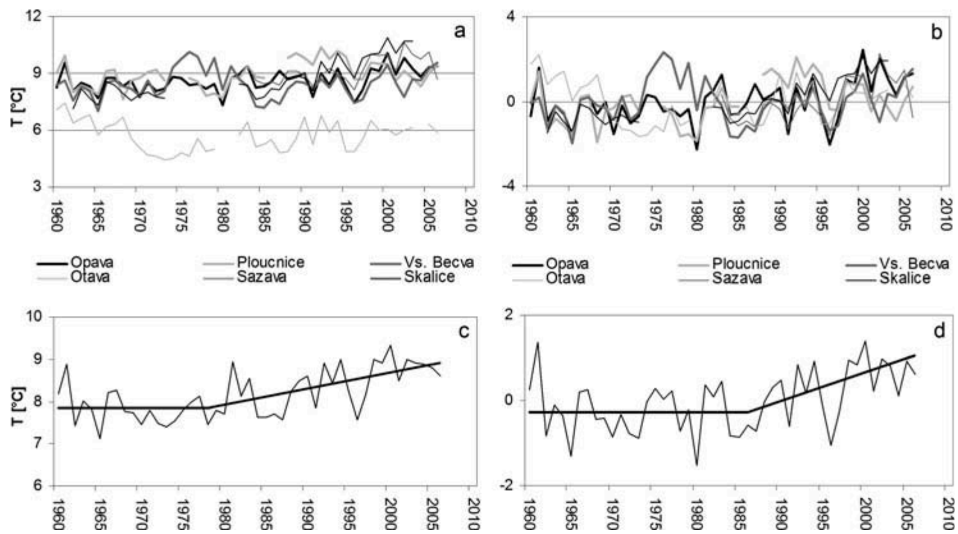

Fig. 3 Long-term trends of average annual water temperature: (a) absolute values, (b) standardization by standard deviation, and test of trend formation for average annual temperatures: (c) absolute values, (d) standardization by standard deviation.

nearest gauging station (CHMI data). The temperature data series were standardized using the standard deviation and their average was tested for the presence and formation of a trend in CPTA software (Procházka *et al.* 2001) at the 0.95 significance level (Fig. 3(b)–(d)). The long-term water quality development was evaluated based on annual maxima, minima and median values (Fig. 4(a)–(f)).

To assess the actual effect of temperature on the selected water quality parameters, the data were analysed in two variants: (a) for all runoff situations, and (b) for situations with similar flows (extreme flows excluded) using a ±20% of average flow (Qav) over the assessed time periods as a cut-off value. The trend characteristics of the evaluated data series remained similar for both of these variants. In most cases, there was a decrease in the dispersion of measured values, but with a strong decrease in the number of data inputs (up to one fifth of the original dataset, Fig. 2(b)). For this reason, only the variant for all runoff situations was further analysed. The dependence of the effect of water temperature and flow on individual water quality parameters and long-term trends in the development of individual parameters was tested for trends at the 0.90 significance level using CPTA software. The reliability value R was determined for each data series.

For assessment of potential point and nonpoint source pollution levels, the indices α and $\beta_{N,P}$ were calculated, as follows:

$$\alpha = \frac{C_1}{C_2} \quad (1)$$

$$\beta_{N,P} = P \times M_{N,P} \quad (2)$$

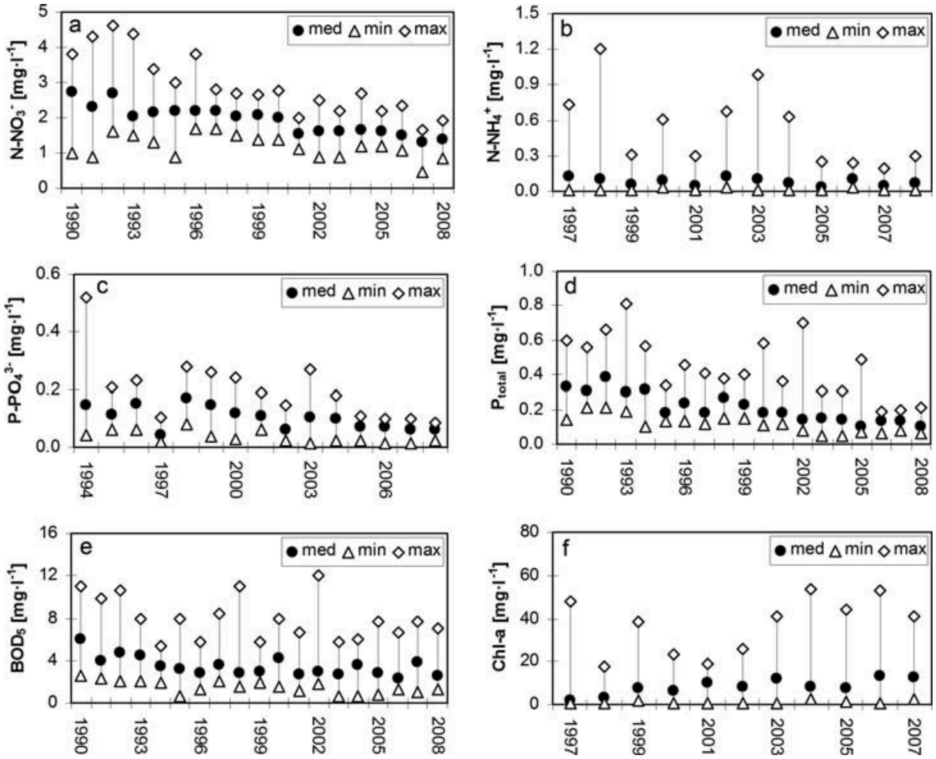

Fig. 4 Long-term development of the assessed water quality parameters in the sampling profiles in the river catchments of (a, b) the Vsetínská Bečva, (c, d) the Úhlava, (e) the Sázava and (f) the Ploučnice.

where C_1 is the concentration of nitrate nitrogen ($N\text{-}NO_3^-$; mg L^{-1}), C_2 is the concentration of total inorganic nitrogen (N; mg L^{-1}), P the percentage of arable land in the river catchment area (%) and $M_{N,P}$ the amount of nitrogen/phosphorus fertilizers applied to arable land (kg ha^{-1} $year^{-1}$). For a value of $\alpha > 0.95$, a prevailing influence of nonpoint source (diffusive) pollution in the river catchment can be expected, while, for a value of $\alpha < 0.90$, the prevailing influence is presumably of point source pollution (Hrabánková *et al.* 2008). The value of index $\beta_{N,P}$ is used to compare individual river catchments for potential loads of inorganic forms of nitrogen/phosphorus from fertilizers applied to arable land (Table 1). Despite the changes in land cover that occurred during the study period 1990–2008 and the extent of fertilizers applied to the arable land, this index allows the comprehensive character of pollution sources and the level of anthropogenic influence on individual river catchments to be evaluated.

3 RESULTS AND DISCUSSION

3.1 Long-term trends in selected water quality parameters

Water temperature measurements from six profiles are shown in Fig. 3. The results of the trend analysis in the studied river catchments show a significant increase in water temperature since 1978, or since 1986 after standardization. The average increase in water temperature was 1.15°C over 28 years. This corresponds to the upper limit obtained from modelling using a pessimistic climate scenario HIRHAM A2 (Novický *et al.* 2009).

To interpret the effects of water temperature and flow on the selected water quality parameters, the time course of these parameters over the study period was evaluated. Trend characteristics were evaluated for all profiles and parameters; examples of the outputs for individual parameters and selected river catchments are shown in Fig. 4. Concentrations of nitrate nitrogen in predominantly agricultural river catchments with a high $\beta_{N,P}$ index (the rivers Jevišovka, Sázava, Skalice, Oslava) have not changed over the long term. This is probably due to the constant or only slightly increasing trends in the application of mineral fertilizers to arable land in the period 1990–2008 (ME 2010), which is consistent with the results obtained by Judová and Janský (2005). In other river catchments, a slightly decreasing trend was found after 1990 (Fig. 4(a)). There was a slight decrease in ammonia nitrogen ($N\text{-}NH_4^+$) concentrations, predominantly in non-agricultural catchments of the rivers Tichá Orlice, Ploučnice, Opava and Vsetínská Bečva; the state of other profiles has not changed in the long term. This decrease was especially distinct in the final profile of the Vsetínská Bečva River, in which up to 90% of the waste water was treated as part of the "Čistá Bečva" (Clean Bečva) Project in 2005 (CF 2002, Table 1) resulting in a 60% decrease in maximum annual concentrations of $N\text{-}NH_4^+$ (Fig. 4(b)).

The amount of phosphate phosphorus ($P\text{-}PO_4^{3-}$) has remained constant in the relatively heterogeneous catchments of the rivers Ploučnice, Jevišovka, Opava and Oslava; in other river catchments there has been a long-term slight decrease. This phenomenon is much more marked for the concentration of total phosphorus (Fig. 4(d)), where a long-term decrease was observed in connection with the gradual intensification of WWTP operations in all profiles; it was less marked only in the agricultural catchments of the rivers Sázava, Jevišovka, Skalice and Oslava. It can be assumed that the amount of total phosphorus is significantly influenced by diffuse sources of pollution, which in heavily-used agricultural river catchments may form up to 60% of total sources (Macleod and Haygarth 2003). The significance of point source pollution with phosphorus and nitrogen has been confirmed by many studies, e.g. Carpenter *et al.* (1998) and Sileika *et al.* (2005).

Analysis of biochemical oxygen demand (BOD_5) showed a slight decrease of values in half of the river catchments, without a distinct effect from land use (the rivers Ploučnice, Jevišovka, Oslavany, Vsetínská Bečva and Sázava); in the other river catchments, BOD_5 did not change over the long term. In most river catchments, the significant increase of chlorophyll-*a* concentration that could have been expected with increasing water temperature and subsequent phytoplankton development also did not occur. A slight increase was observed in the Ploučnice catchment only (Fig. 4(f)), and in the Jevišovka catchment a slight decrease was found that may, however, not be explained from the available data.

3.2 Effects of water temperature on selected water quality parameters

Examples of the analysis of the dependence of the studied water quality parameters on water temperature are presented in Fig. 5. It can be seen that in all studied profiles a continuous decrease in the concentration of nitrate nitrogen with temperature occurs for agricultural river catchments with β_N > 1000 by 60–80% (Fig. 5(a)) and for others by 20–40% associated with the extreme values of water temperature during the year. The hypothesis that water temperature has an effect on the efficiency of $N\text{-}NO_3^-$ breakdown in waste water treatment plants was tested in terms of potential point source pollution. However, the results of 4-year series from WWTPs with population equivalent capacities of 1500–50 000 did not show any correlation. The decrease is thus probably caused by the intensity of assimilation processes of biomass growth (especially agricultural crops) during the vegetation season. An additional effect arising from the assimilation of autotrophic communities in the river channel may also be expected, and was documented by the relatively strong negative dependence of chlorophyll-*a* concentration on nitrate nitrogen. Van Vliet and Zwolsman (2008) came to the same conclusions in the Moselle River catchment. The concentration of ammonia nitrogen showed a similar decrease by 70–90% in seven of our profiles regardless of the character of the river catchment, but with the difference that the decrease was most obvious in water temperatures in the range 0–7°C (Fig. 5(b)), with intensive nitrification processes the rest of the year. Only in the Otava River catchment, with the smallest nutrient load, was there a slight increase in the $N\text{-}NH_4^+$ content at water temperatures above 15°C, but the maximum concentrations were very small (~0.03 mg L^{-1}).

In general, there was no clear dependence of phosphate or total phosphorus concentrations on temperature. The only exceptions are the agricultural catchments of the rivers Oslava and Skalice, where a very slightly increasing trend at temperatures higher than 10°C (corresponding to the start of the vegetation period) was found, especially for total phosphorus (Fig. 4(d)). As a direct effect of point source pollution, a dependence of breakdown of phosphorus on water temperature in WWTP was not manifested. There does seem to be an influence of surface runoff in connection with snowmelt or spring/summer precipitation, though it was not confirmed in phosphorus–discharge dependence during high flows. However, in other river catchments with β_P > 1000 this dependence was not found and additional analyses are needed to explain this increase.

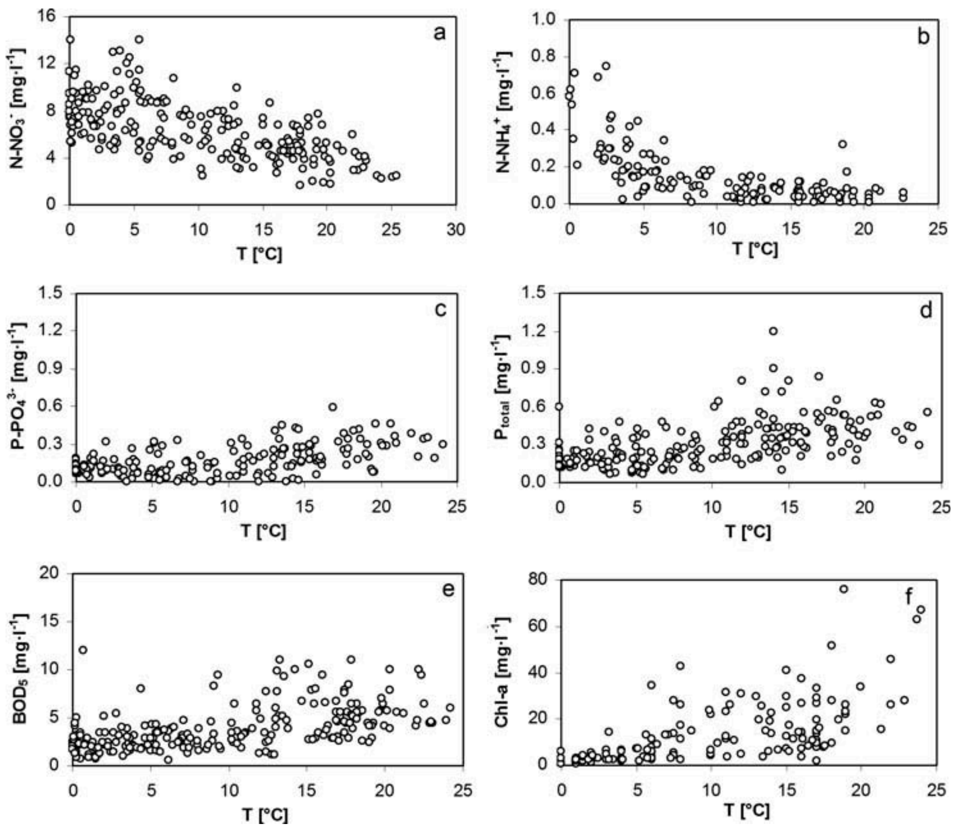

Fig. 5 Dependence of the studied water quality parameters on water temperature in the rivers (a, e) Sázava, (b) Ploučnice, (c, d) Skalice and (f) Úhlava.

Similarly, a dependence of biochemical oxygen demand (BOD_5) on temperature was not found, but random extremes were observed during the year. The exceptions were the rivers Skalice and Sázava (Fig. 5(e)), where a very slight dependence was observed, but because of insufficient data on the forms of organic pollution it was not possible to satisfactorily interpret this increase. In contrast, a significant dependence of chlorophyll-*a* concentration on water temperature was observed in 50% of profiles (Fig. 5(f)), where a 10- to 20-fold increase during the vegetation period occurred, predominantly in agricultural river catchments. Similar conclusions were made by Desortová and Punčochář (2011). The exception was the Jevišovka River, where the amount of chlorophyll-*a* did not change with temperature. Specific geological conditions (the bedrock formed predominantly by Tertiary sediments), which are reflected in the highest content of suspended particles among all the studied river catchments, are the probable reason, as they can effectively decrease the penetration of light in the water and prevent more massive cyanobacteria and algae growth in the vegetation period. Similarly, no dependence was found in shaded river catchments with a predominance of forest vegetation (Otava, Opava and Vsetínská Bečva) in the river surroundings.

3.3 Effects of flow on selected parameters of water quality

In addition to increased water temperature, other possible impacts of climate change that can be expected are mainly the higher frequencies and duration of extreme runoff situations. Although pollution with toxic metals and specific organic substances can affect the water quality to a great extent during floods, this is usually a short-term effect. However, periods of drought are mostly of intermediate character (weeks to months) and their effect is more focused on stream nutrient and oxygen regimes (Whitehead *et al.* 2009). As a consequence of climate change, a strong decrease in total runoff from the land may occur during the year (Hanel *et al.* 2012), with adverse effects on water quality and changes during the year (Mimikou *et al.* 2000). It is clear from the analysis shown in Fig. 6 that selected parameters of the nutrient regime are much more affected

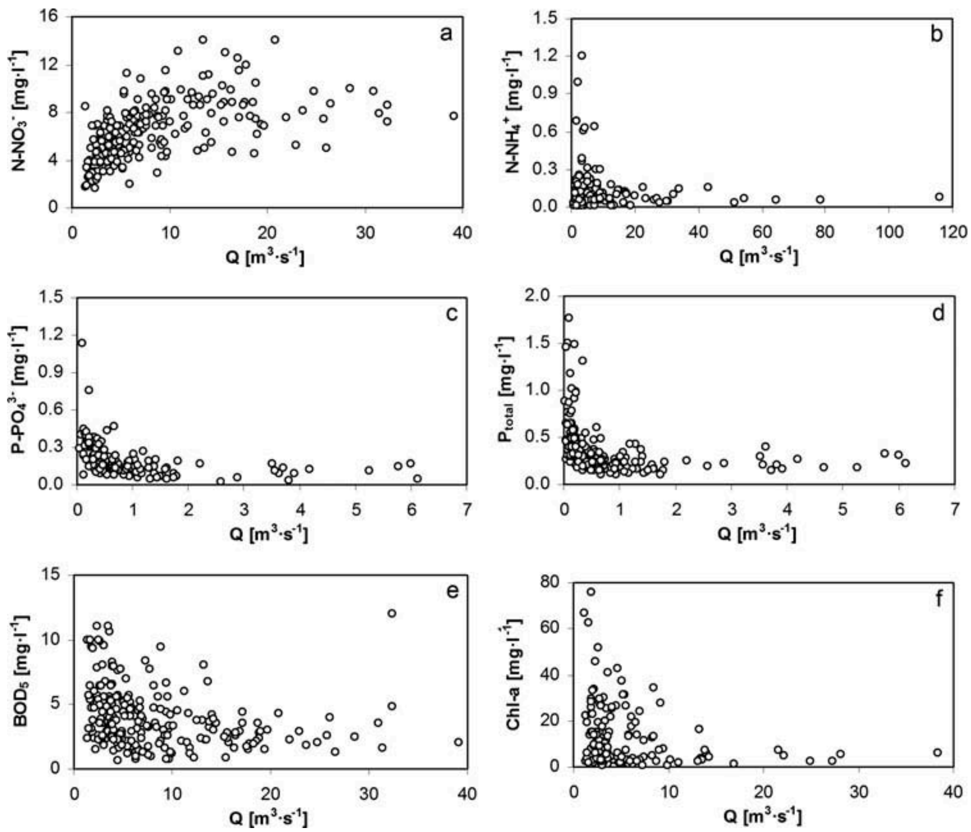

Fig. 6 The dependence of the studied water quality parameters on flow in the rivers (a, e) Sázava, (b) Vsetínská Bečva, (c, d) Jevišovka and (f) Úhlava.

by extreme runoff situations (especially by periods of drought) than by water temperature itself.

In agricultural river catchments with $\beta_N > 2000$, a significant increase in nitrate nitrogen during increased flows occurred, with an increase of 100–300% (in comparison to minimum flows) in five river catchments (Fig. 6(a)). Van Vliet and Zwolsman (2008) and Judová and Janský (2005) also reported the exponential growth of $N\text{-}NO_3^-$ concentration dependent on flow as a consequence of surface runoff from arable land during heavy rains. Considering the short-term effect of floods and the range of the recorded values, this temporary increase does not appear to be problematic. It should be noted, however, that the assessment of pollution sources in a river catchment according to the α coefficient cannot be considered as a general approach. In the Opava and Otava river catchments, with a minimum area of arable land, the coefficient $\alpha > 0.95$ corresponds to a river catchment with predominant nonpoint source pollution. However, higher concentrations of nitrate nitrogen depending on the flow were not found here. This is because this diffusive pollution comes predominantly from pastures with extensive livestock rearing, and the nature of the nitrogen transport is different from the arable land river catchments with $\beta_N > 2000$. In the river catchments with predominant point source pollution, concentrations of ammonia nitrogen were strongly dependent on the flow, since insufficient dilution of waste waters occurs at low flows (Fig. 6(b)). This phenomenon is typical for the winter time, when the nitrification process is suppressed (Fig. 5(b)). A significant 250–300% increase in $N\text{-}NH_4^+$ concentrations was found in the catchments of Jevišovka (α = 0.941) and Oslava (α = 0.952) and up to 1000% in the case of Vsetínská Bečva (α = 0.938), with a sharp rise during the flow below the long-term normal Qa. However, it should be noted that in the Vsetínská Bečva River, all the values of $N\text{-}NH_4^+ > 0.3$ mg L^{-1} were recorded prior to the "Čistá Bečva" project and, in contrast to the Jevišovka River, the current situation is already satisfactory in that light. The Jevišovka River catchment, despite the high ratio of arable land (high β_N index, positive dependence of $N\text{-}NO_3^-$ runoff from the river catchment), is heavily loaded with point source pollution as well as only 42% of the population is connected to a WWTP (Table 1).

River loading with phosphate and total phosphorus did not show a general dependence on predominant sources of pollution in the river catchment. A strong dependence of the concentrations of both phosphorus forms on flow, with increases of 100–300% resulting from flow decreases below the long-term normal Qa, was found in eight profiles. This corresponds to results from Whitehead *et al.* (2009) and van Vliet and Zwolsman (2008). The best relationships were found in the river catchments loaded with point source pollution, i.e. the Vsetínská Bečva River catchment (before the completion of the "Čistá Bečva" project) and the Jevišovka River catchment. In general, there is a clear increase in total phosphorus concentrations (Fig. 6(d)) in most of the river catchments. A similar dependence was also found for the Skalice and Sázava River catchments, which are predominantly loaded with nonpoint source pollution. However, the expected strong effect of phosphorus runoff from arable land at higher flows, described e.g. by Jarvie *et al.* (2010), was not observed. The study by Jarvie *et al*. (2010) was on a very small river catchment (area: 9.9 km^2) and with a less complicated system of connections. Nevertheless, the concentrations of total phosphorus measured at flows higher than Qa fluctuated more than P-PO_4^{3-} concentrations, showing possible different sources of origin. A more precise differentiation of a real influence of point and nonpoint source pollution without additional data is rather difficult and burdened with high uncertainty (de Wit *et al*. 2002).

Apart from the Sázava River catchment (Fig. 6(e)), the expected dilution effect of increased flows on BOD_5 was not observed, and seems to be independent of the flow. This is in contrast to chlorophyll-*a* concentrations, which show a very close dependence. The decrease in chlorophyll-*a* concentration with increasing flow in all studied river catchments within the extremes of the measured flows was 80–90%. In the case of a long-term hydrological drought, undesirable processes connected with changes to the oxygen regime and that influence the ecological status of the stream may occur in connection with water temperature increases (Williams *et al.* 2000, Cox and Whitehead 2009, Desortová and Punčochář 2011).

4 CONCLUSIONS

Since 1990, the water quality in the Czech rivers assessed herein has demonstrably improved, especially in both forms of inorganic nitrogen and total phosphorus, particularly in non-agricultural river catchments with predominant point source pollution, where concentrations decreased by 20–60% from 1990 to 2008. However, the results of regular monthly water analyses in 10 river catchments with little anthropogenic influence exhibit significant adverse effects from low flow and increased water temperature on selected parameters of water quality in the same period.

From the viewpoint of climate change impacts on water quality, reflected in the increase in water temperature since the mid-1980s, a further breakdown of inorganic nitrogen in water can be expected with increasing water temperature. However, the results here indicate that the effect will be rather marginal in contrast with the frequency of occurrence and duration of subnormal flows, which seem to be the limiting factors for ammonia nitrogen concentrations. In the river catchments loaded with point source pollution, strongly increased concentrations (up to 10 times) could thus be expected. The concentrations of nitrate nitrogen do not appear to be problematic as a result of the anticipated impacts of climate change.

Similarly, the concentrations of dissolved phosphorus in general proved to be independent of water temperature, but demonstrated a very close relationship with flow, showing a significant increase (up to three times) during flows below the long-term normal Qa, regardless of the type of prevailing pollution in the river catchment. Almost no dependence on the change in water temperature and river flow was found for biochemical oxygen demand (BOD_5), which almost did not change within the assessed period. No significant changes in BOD_5 can thus be expected assuming current land management over the intermediate time horizon.

The concentrations of chlorophyll-*a* were very sensitive to increases in water temperature and decreases in river flow in the assessed river catchments. Although the concentrations did not change after 1997, this sensitivity implies that a significant increase with consequent impacts on the ecological status of streams can be expected during the prolonged summer hydrological droughts and anticipated 2–3°C increase in water temperature by the year 2050.

It can be concluded that the water quality parameters assessed here are much more affected by changes in river flow than by temperature of water itself. From the intermediate- to long-term view of climate change, periods of hydrological drought will likely be the determining factor in the development of water quality in streams with little anthropogenic influence in the Czech Republic.

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