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CHANGES OF PHYSICOCHEMICAL PARAMETERS AND PHYTOPLANKTON IN WATER OF A SUBMOUNTAIN DAM RESERVOIR – EFFECT OF LATE SUMMER STORMFLOW

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Abstract: Physicochemical parameters of water and phytoplankton composition were studied in the dimictic, submountain Dobczyce Reservoir (southern Poland) affected by summer stormflow, which took place in September 2007. During summer (except September) temperature, pH, dissolved oxygen, and carbonates showed vertical differentiation. Stormwater flow through the system had a destabilizing effect on summer stratification. It diluted the concentrations of salts (sulphate and chloride) and slightly increased the concentration of nutrients in the reservoir. In phytoplankton some changes in the dominant species among the Cyanobacteria group were noted.

INTRODUCTION

It is well known that hydrological conditions influence various processes in dam reservoirs. Seasonal hydrological fluctuations effect both the physical, chemical and biological features of reservoirs [4, 5, 14, 17, 20, 21]. According to Bonell [2], flow pathways that dominate during storm or snowmelt events determine the surface water chemistry both during and after the event. It is also the most important feature affecting the diversity and dynamics of phytoplankton [18]. Changes in retention time might be crucial for changes in the phytoplankton community composition and density both in shallow [8] and in deep water bodies [6].

Floods are natural, periodically occurring events. However, in recent years/decades, increased frequencies of heavy rainfall and flood events in southern Poland have been observed. Because heavy precipitation and maximum flow in rivers in southern Poland usually occur in summer, summer stormflow strongly disturbs the typical summer stratification that occurs in submountain reservoirs. Literature focusing on the effects of periodic flood events on reservoir physicochemical and biological features is scarce [6]. In fact, only a few studies examine the effect of floods on phytoplankton in dam reservoirs, especially the deep ones [16, 25, 26]. This issue is an important one since it is predicted that global warming will result in heavier precipitation and more frequent and violent floods.

The aim of the current study was to present the effects of stormwater on the disturbance of late summer stratification and changes in the water chemistry, phytoplankton composition and biomass (chlorophyll *a*) in a dimictic, submountain Polish reservoir.

STUDY AREA

The Dobczyce Reservoir (49°52'N, 20°02'E, alt. 270 m) is a deep, submountain dam reservoir located in southern Poland (Fig. 1). It was built on the Raba River (Wisła basin) in 1986. It is a drinking water reservoir for the city of Krakow. It has a length 10 km, an area of c. 1000 ha, a mean depth of 11 m (max. c. 30 m), and a capacity of 99.2 mln m^3. The Raba River supplies 88.6% of the total inflow. The average water exchange is 3.6 times a year [12]. The reservoir is eutrophic and dimictic in its lower, deeper part where the circulation of the water during the spring and autumn takes place. In summer thermal and oxygen stratification occurs. The metalimnion occurs usually at the depths of between 6–8 m [14]. According to Materek [11], the 'flood wave' is characterized as flows greater than 300 $m^3 \cdot s^{-1}$. Flood waves were observed several times in the Raba River: in 1987 (max water flow 451 $m^3 \cdot s^{-1}$), in 1996 (529 $m^3 \cdot s^{-1}$), in 1997 (884 $m^3 \cdot s^{-1}$), in 2001 (484 $m^3 \cdot s^{-1}$) [6]. The data concerning years 2005 and 2007 was obtained from Regional Water Management Board in Krakow and present as follows 348 $m^3 \cdot s^{-1}$, 430 $m^3 \cdot s^{-1}$ respectively.

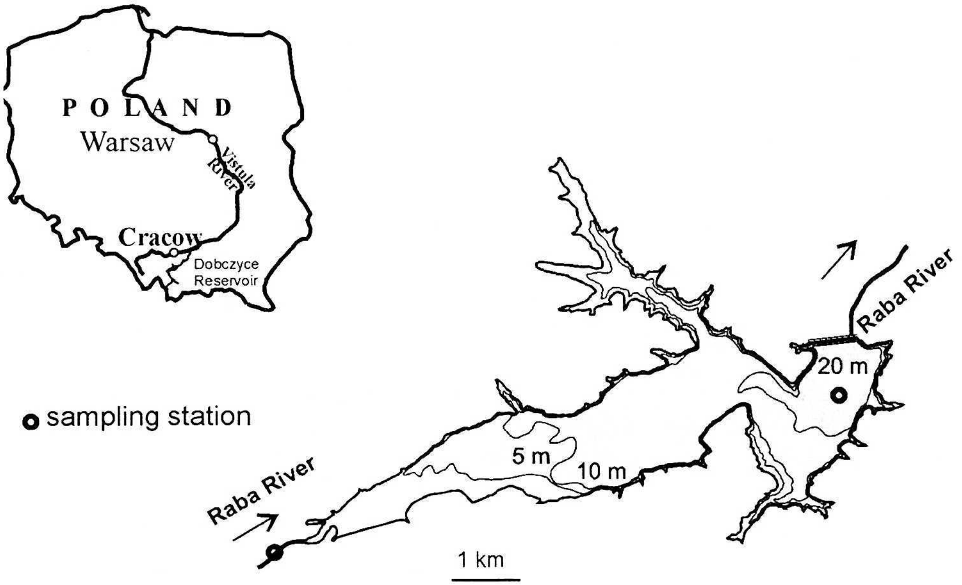

Fig. 1. Location of the sampling stations

MATERIAL AND METHODS

Samples for physicochemical parameters and phytoplankton were collected monthly from January to December 2007 from the deepest part of the Dobczyce Reservoir (depth ca. 26 m; Fig. 1). Samples to examine the effects of the flood were taken 3 days after the flood event (September 19, 2007). At the same time, samples for physicochemical analyses were collected from the Raba River close to the inlet to the reservoir (Fig. 1). Samples for physicochemical parameters and chlorophyll *a* measurements were taken using a bathometer at depths of 0, 2.5, 5, 7.5, 10, 12.5, 15, 20 and 1 m above the bottom (108 samples in total). Samples for qualitative and quantitative analyses of phytoplankton were taken using a 5 dm^3 sampler from the epilimnion.

The following parameters were measured: water temperature, conductivity, pH, dissolved oxygen, anions (chloride, sulphate, hydrocarbanate) and nutrients (P-tot, NO_3^-, $N\text{-}NH_4^+$). Water temperature, conductivity, and pH were measured *in situ*. Analyses of anions: chloride, sulphate, hydrocarbonate, and nitrate were conducted using ion chromatography (DIONEX, IC25 Ion Chromatograph). Dissolved oxygen was determined according to the Winkler method. Ammonia was analyzed with the nesslerization method, while P-tot (after mineralization) was measured using the molybdenum blue method [1]. Chlorophyll *a* was extracted in hot 90% ethanol and measured spectrophotometrically at 665 nm and at 750 nm [15]. Samples of phytoplankton were fixed with Lugol's solution and concentrated by sedimentation from a 1 dm^3 sample [19]. Algae were counted according to Lund *et al.* [9].

Daily discharge data for the Raba River were recorded from Regional Water Management Board in Krakow. To calculate the relationship between discharge of the Raba River and physicochemical parameters in the Dobczyce Reservoir, monthly water discharge in the Raba River was calculated. Statistica 8.0 was used for statistical analysis.

RESULTS

Discharge and physicochemical parameters in the Raba River

Mean annual water discharge in the Raba River near the inlet to the Dobczyce Reservoir was 12.7 $m^3 \cdot s^{-1}$ in 2007. The lowest mean water discharge was recorded from April to July (2.8–4.5 $m^3 \cdot s^{-1}$), while discharge was the highest in September (mean 42.6 $m^3 \cdot s^{-1}$). Between 6–11 September, stormflow discharge ranged from 85 to 430 $m^3 \cdot s^{-1}$ (maximum on 8 September; Fig. 2). In total, 90 mln m^3 of water reached the reservoir in that period. It constituted 81% of the reservoir capacity. Physicochemical parameters of water during

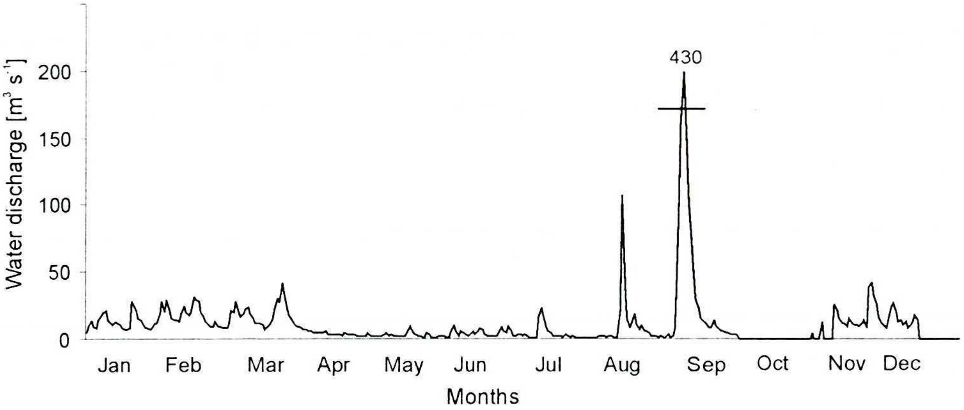

Fig. 2. Daily water discharge in the Raba River in 2007

that time (11 September) were as follows: temperature 12°C, conductivity 251 μS·cm^{-1}, pH 7.9, oxygen dissolved 9.9 mg·dm^{-3}, chlorides 5.9 mg·dm^{-3}, hydrocarbonates 167.8 mg·dm^{-3}, sulphates 19.2 mg·dm^{-3}, NO_3^- 4.6 mg·dm^{-3}, N-NH_4^+ 0.39 mg·dm^{-3}, and P-tot 0.046 mg×dm^{-3}.

Physicochemical and biological parameters of the reservoir water

Water transparency (Secchi-depth measurements) ranged from 0.55 to 5.7 m from January to December 2007. The lowest transparency was found in September (the flood event; 0.55 m) and in November (0.8 m), whereas the highest occurred in summer from June to August (3.1–5.7 m).

Temperature, pH, and dissolved oxygen showed seasonal variations (Fig. 3). According to those parameters variations, spring and autumn overturn in 2007 occurred in April and November, while summer stratification occurred from May to October (except September). During stratification, three distinct layers were distinguishable: the epilimnion (0–5 m), metalimnion (7.5–12.5 m), and hypolimnion (from 15 to the bottom). Water temperature was the highest in the epilimnion and decreased to the bottom from May to

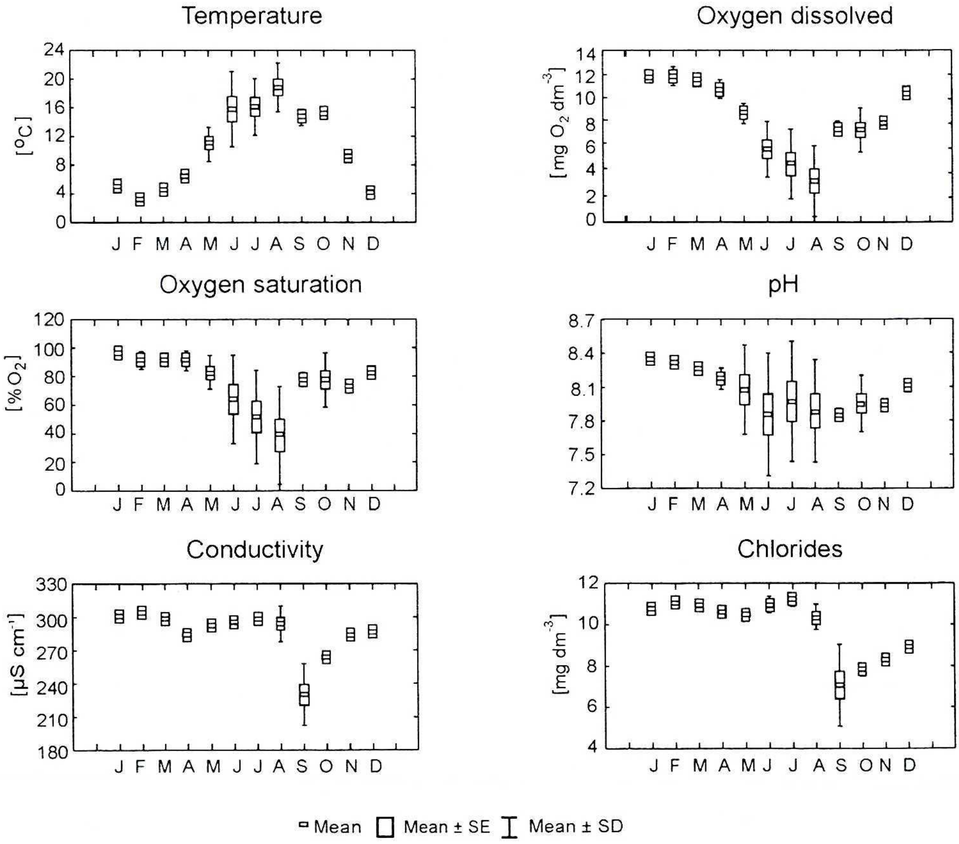

Fig. 3. Mean values, standard deviations (SD) and standard error (SE) of temperature, dissolved oxygen, oxygen saturation, conductivity, pH, and chlorides in the water of the Dobczyce Reservoir in 2007

August (Fig. 4). In August, the temperature of the surface water was 22°C, while near the bottom it was 12.8°C. Summer stormflow (September) affected the water temperature. It decreased from the surface to a depth of 15 m (the range of decrease was 4.5 to 6.1°C), while close to the bottom (at a depth of 25 m) it slightly increased (by ca. 1°C, Fig. 4). In October more homogenous temperature in the water column occurred.

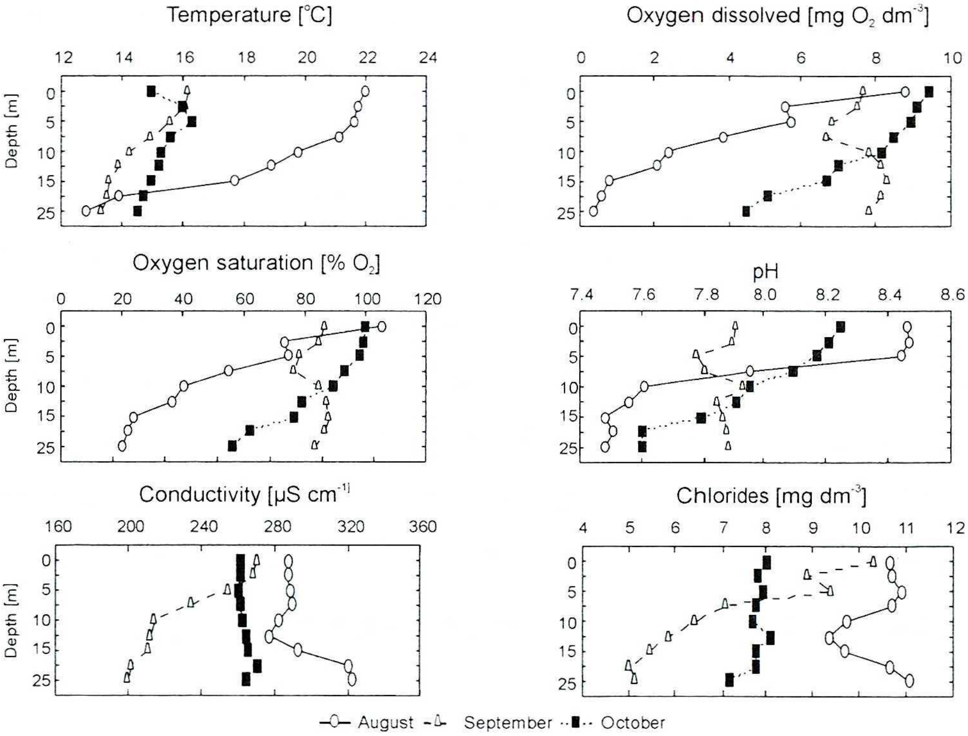

Fig. 4. Temperature, dissolved oxygen, oxygen saturation, conductivity, pH, and chlorides in the water column of the Dobczyce Reservoir in August, September, and November 2007

pH of the water was always nearly neutral or alkaline (pH 7.3–8.5) (Fig. 3). In the winter months, spring and autumn overturn, pH ranged from 7.9–8.3 and was characterized by low variability in the water column (CV = 0.06–1.1). During summer stratification (except September) great pH variability in the water column was found (Fig. 4). It was higher in the epilimnion (pH 8.1–8.6) and lower in the hypolimnion (pH 7.3–7.8). In September similar pH (7.8–7.9) in the water column was found.

The water was well oxygenated during winter as well as spring and autumn overturn (8.0–12.8 mg·dm^{-3}, Fig. 3). In summer (except September) the concentration of dissolved oxygen was higher in the epilimnion (oxygen saturation reached ca. 103% in June and August) compared to the meta- and hypolimnion (Fig. 4). Hypolimnion was poorly oxygenated (0.4– 3.8 mg·dm^{-3} from June to August). In September (the flood event) the whole water mass was moderately well oxygenated (6.7–8.3 mg·dm^{-3}, oxygen saturation 69–83%, Fig. 4). Subsequently, in October, typical summer oxygen stratification was again present (4.4–9.4 mg·dm^{-3}, oxygen saturation 45–97%).

Conductivity (reflecting salt concentration) ranged from 200 to 332 $\mu S \cdot cm^{-1}$ (Fig. 3). Higher salt concentrations (expressed by conductivities of 281–306 $\mu S \cdot cm^{-1}$) occurred in the periods January- June, November, and December, with low variability in the water column (CV = 0.2–0.7). The lowest salt concentrations were found in September (the flood event, 200–270 $\mu S \cdot cm^{-1}$) and October (260–270 $\mu S \cdot cm^{-1}$). In summer (August, September) great variability in salt concentrations throughout the water column occurred (Fig. 4). In August salt concentrations increased from the surface to the bottom (277–322 $\mu S \cdot cm^{-1}$) except at a depth of 15 m, while conversely levels decreased in September. In October salt concentrations were homogenous in the water column.

Concentrations of chlorides (5–10.7 $mg \cdot dm^{-3}$) and sulphates (15.7–24.3 $mg \cdot dm^{-3}$) showed characteristically low variability in the water column during the year (except in September; Figs. 3 and 5). Higher levels were found from January to August, while the lowest concentration occurred in September during the flood event (chloride 5–10.3 $mg \cdot dm^{-3}$; sulphate 15.7–22.9 $mg \cdot dm^{-3}$). In September, their variability in the water column was considerable. Their amounts decreased from the epilimnion to the hypolimnion (Figs 4 and 6). Increased chloride and sulphate concentrations were observed from October to December.

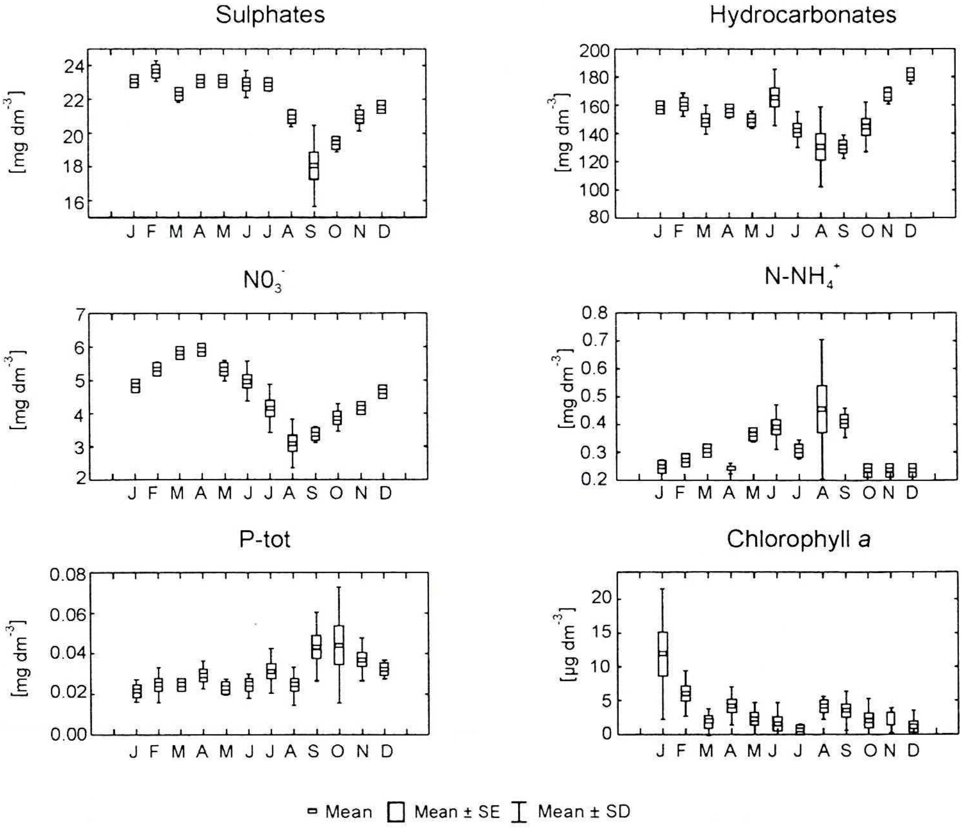

Fig. 5. Mean values, standard deviations (SD) and standard error (SE) of sulphates, hydrocarbonates, NO$_3^-$, N-NH$_4^+$, and P-tot concentrations in the water of the Dobczyce Reservoir in 2007

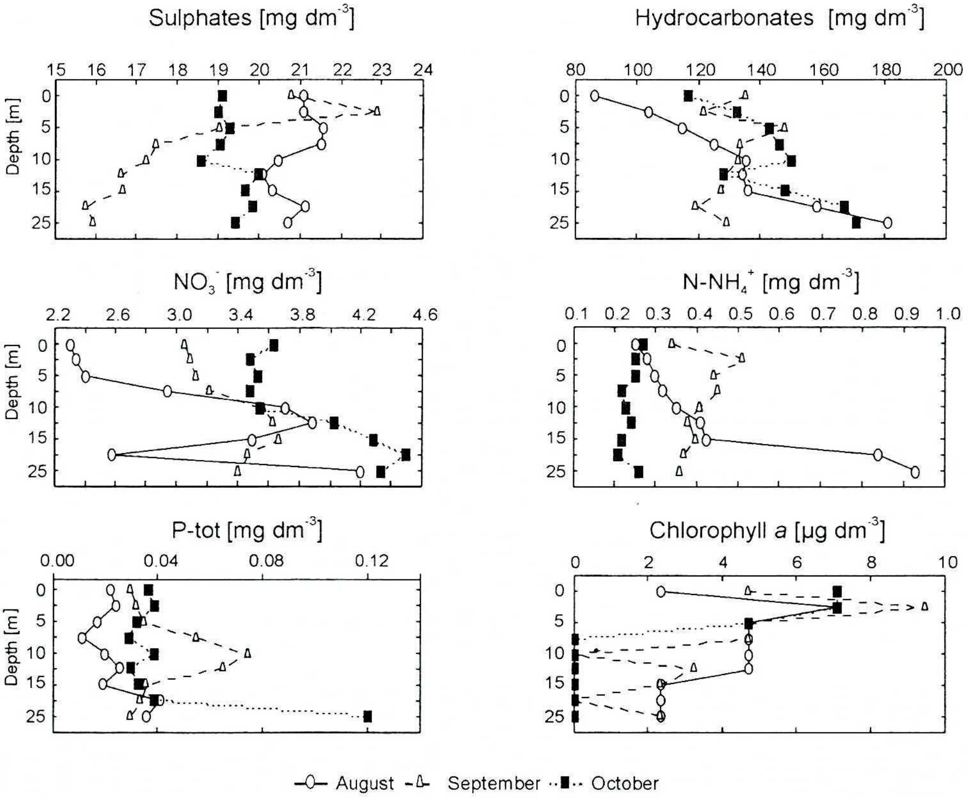

Fig. 6. The concentrations of sulphate, hydrocarbonate, NO_3^-, N-NH_4^+, and P-tot in the water column of the Dobczyce Reservoir in August, September, and November 2007

Hydrocarbonates ranged from 86.1 to 192.0 mg·dm^{-3} (Fig. 5) and were characterized by higher vertical variability compared to chlorides and sulphates. Higher hydrocarbonate concentrations (mean 150–180.5 mg·dm^{-3}) occurred in the whole water mass in winter, spring and autumn overturn, as well as in the metalimnion and hypolimnion in summer (except in September; peak 191 mg·dm^{-3} in June at the depth of 10–12.5 m). The lowest concentrations of hydrocarbonates were found in the epilimnion in summer (in August 86 mg·dm^{-3}; Fig. 6). In August and October, hydrocarbonate concentrations increased from the surface to the bottom (Fig. 6). During the September flood event, the concentrations of hydrocarbonates were low (128–148 mg·dm^{-3}) and more homogenous in the whole water mass.

The highest nitrate (NO_3^-) concentrations in the water mass occurred in the winter months, and during the spring and autumn overturn (4.0–5.9 mg·dm^{-3}), while concentrations were the lowest in August (2.3–3.8 mg·dm^{-3}, except the concentrations at 25 m, Fig. 5). During summer stratification vertical variability in nitrate concentrations was observed (Fig. 6). Concentrations were lower in the epilimnion than in the hypolimnion (Fig. 6). In September, during the flood event, nitrate concentrations (3.0–3.7 mg·dm^{-3}) in the water (especially in the epilimnion) were higher compared to August.

Ammonia nitrogen ($N\text{-}NH_4^+$) ranged from 0.20 to 0.93 mg·dm^{-3} in the reservoir (Fig. 5). Low $N\text{-}NH_4^+$ concentrations occurred in January, February, April, September, and from October to December (mean 0.23–0.27 mg·dm^{-3}), while the highest concentrations occurred in the hypolimnion in August (0.25–0.93 mg·dm^{-3}). In September during the flood event, $N\text{-}NH_4^+$ concentrations were low (0.34–0.51 mg·dm^{-3}) and rather homogenous in the water column. A decrease in $N\text{-}NH_4^+$ concentration in the hypolimnion compared to August was observed (Fig. 6).

Concentrations of P-tot were low (mean 0.022–0.025 mg·dm^{-3}) in the winter months (January-March), during spring mixing (May), and in summer (June, August; Figs 5 and 6). The highest P-tot concentrations were found during the flood event in September (0.055–0.075 mg·dm^{-3} at the depths of 7.5–12.5 m) and in the hypolimnion in October (0.12 mg·dm^{-3} at the depth of 25 m).

A statistical analysis showed the relationships between the Raba River discharge and selected parameters in the water of the Dobczyce Reservoir, i.e.: a significant negative correlation with water transparency ($r = -0.6$, $p < 0.05$), conductivity ($r = -0.71$, $p < 0.02$), chloride ($r = -0.61$, $p < 0.05$), and sulphates ($r = -0.66$, $p < 0.02$), and a significant positive relationship with P-tot ($r = 0.62$, $p < 0.05$).

The highest chlorophyll *a* concentration and variability in the water column was noted in January, whereas the lowest occurred in July. Diatoms constituted the dominant group in January. Almost 80% of total density and 90% of total biomass of phytoplankton was composed of *Stephanodiscus neoastrea* "complex" Hakansson & Hickel. Subsequent months were characterized by generally low concentrations of chlorophyll *a*. In August, the dominant group was the blue-green algae (mostly *Merismopedia tenuissima* Lemm. and *Microcystis* spp.) and cryptophytes (*Cryptomonas* spp.). The concentrations of chlorophyll *a* in September were insignificantly higher compared to August. The dominant groups were again the blue-green algae and cryptophytes. However, changes were observed in the dominant species among blue-green algae (*Woronichinia naegeliana* (Unger) Elenkin. was dominant) but not among the cryptophytes.

The highest concentration of chlorophyll *a* was noted in the upper part of epilimnion (0–5 m). In September, chlorophyll *a* concentrations reached 9.5 μg·dm^{-3} (the highest concentration at 2.5 m). In August and October, there were insignificantly lower maxima – 7.1 μg·dm^{-3} (both months' max. concentration at 2.5 m). We observed decreases in chlorophyll *a* concentrations at the deepest water level (from 7.5 m to the bottom) in October.

DISCUSSION

Mean annual water discharge in the Raba River in 2007 was higher compared to those found during 1986–1999 (10.65 m^3·s^{-1}) [14], but lower than those found in 1997 (14.86 m^3·s^{-1}) [13] when the greatest flood event in the 20th century was noted. Maximum water discharge in the Raba River in September 2007 was twice as low as that recorded during a flood in July 1997 (884 m^3·s^{-1}) [13]. Between 6–11 September 2007, about 90 mln m^3 of water entered the reservoir, making up about 81% of the total reservoir capacity. Such high water inflow affects summer stratification in the deeper part of the reservoir.

Our results indicated that the most significant variation in water transparency of the Dobczyce Reservoir was inversely related to the water discharge of the Raba River.

In general, water transparency in the deep dam reservoirs in southern Poland is more strongly related to the riverine water discharge rather than with primary production [14]. The lowest water transparency was found in the Dobczyce Reservoir at the time of the enhanced Raba River water discharge (September). Similar phenomenon was found in the Dobczyce Reservoir during the flood in 1997 [6, 13], and in other reservoirs [4, 10]. During the flood events, high loads of suspended matter leached from the catchment basins by stormwater are transported through the reservoir, causing reduced water transparency [4, 6].

Temperature, pH and dissolved oxygen in the Dobczyce Reservoir showed seasonal patterns typical of dimictic submountain dam reservoirs in Poland [14]. pH ranged from slightly neutral to alkaline, related to the geochemical background of the catchment basin. Temperature, pH, and oxygen dissolved showed summer stratification. Summer stormflow (September) caused destabilizing effects on the water mass and disturbed stratification. At that time, the above mentioned parameters showed little variability in the water column. The reservoir became riverine in nature. An inflow of colder Raba River stormwater (12°C) in September affected a decrease of water temperature from the surface to the depth of 15 m. This effect of stormwater on the thermal gradient (increase or decrease) in dam reservoirs was also stated by Tüzün and İnce [20] and Godlewska *et al.* [6]. The summer stormflow affected also a decrease of pH in the epi- and metalimnion, and an increase in the hypolimnion of the Dobczyce Reservoir (compared to August). A similar decrease in pH during a flood was observed by Faithful and Griffiths [4]. However, it was only observed in the mid-column, the area of water flow through the Lake Dalrymple (dam reservoir in north Queensland, Australia). The water of the Dobczyce Reservoir was well oxygenated in the majority of the year. The depletion of oxygen occurred in the hypolimnion only in summer as a result of the decomposition of organic matter and the oxidation of ammonium. Such summer oxygen depletion is typical for the Dobczyce Reservoir [14]. Well oxygenated stormwater (9.92 $mg \cdot dm^{-3}$) flowing through the reservoir in September improved oxygen conditions in the hypolimnion. Similar re-oxygenation of hypolimnetic water was observed earlier in the Dobczyce Reservoir during the flood in 1997 [6]. Conversely, the lack or only slight re-oxygenation of anoxic hypolimnetic water was observed in Lake Dalrymple [4]. The authors explained that water flow through the reservoir affected only the mid-column section but not the hypolimnetic water. Thus the extent of re-oxygenation of the hypolimnion depends on the vertical range of water flow through the dam reservoir during a flood event.

The concentration of salts (expressed as conductivity) in the water of the Dobczyce Reservoir was the lowest in September during the flood event, which reflected the conductivity of the Raba River stormwater. Low conductivity of reservoir waters during flood events was also observed by Mazurkiewicz and Żurek [13] as well as by Faithful and Griffiths [4]. The latter authors found out that stormwater flowing through the reservoir (Lake Dalrymple, Australia) resulted in characteristically low conductivity and high turbidity. The lowest conductivity occurred with the most highly turbid water. Sulphate and chloride concentrations showed similar patterns of occurrence in the water of the Dobczyce Reservoir. Their concentrations showed little seasonal and vertical variability and were inversely related to the Raba River discharge. Summer stormwater caused dilution of SO_4^{2-}, Cl^-, and HCO_3^- in the water column of the Dobczyce Reservoir. Similarly reduced concentrations of Cl^- and SO_4^{2-} in streamflow in response to rain events were found by Brown *et al.* [3] and Żelazny [27]. Considerable dissolution of Cl^- concentrations (from 275 to 36 $mg \cdot dm^{-3}$) in the Vistula River (Poland) during summer stormflow in 1997 was found by Mazurkiewicz and Żurek [13]. According to Brown *et al.* [3], dilution of stormflow is more closely related to the timing of the contribution of the event-water component to stormflow than by the volume of discharge in the stream channel. In most catchments, the maximum stormwater contributions occurred immediately after the hydrograph peak.

The seasonal patterns of nitrates and P-tot concentrations in the water of the Dobczyce Reservoir were typical of submountain dam reservoirs [14]. They are usually related to the biological activity of primary producers. In September, slight increases in NO_3^- and P-tot concentrations in the water of the Dobczyce Reservoir indicated higher leaching from the catchment during heavy rainfalls. Concentration of P-tot in the water of the Dobczyce Reservoir was positively related to the Raba River discharge. The relationship between P-tot concentration in dam reservoir and water inflow was also found by Tüzün and İnce [20]. Elevated amounts of N-tot and P-tot in the water of the Vistula River during the flood of 1997 was found by Mazurkiewicz and Żurek [13]. According to Żelazny [27], the leaching of macroelements and NO_3^- from soils is higher when stormwater easily infiltrates deeper soil layers than when the infiltration is limited (frozen soils). According to Faithful and Griffiths [4], a great part of P-tot (almost all) and N-tot (more than 50%) is transported with suspended particulate matter in stormwater (Lake Dalrymple, Australia). However, other parameters like water temperature and dissolved oxygen concentration may also influence P-tot concentration in the water. In summer, ammonium concentrations in the hypolimnion of the Dobczyce Reservoir were high. This results from digenesis processes occurring at the bottom. In September the water inflow through the system caused considerable dilution of ammonium in the hypolimnion.

High water influxes to dam reservoirs are responsible for the development of fast growing algal species [7]. Similar observations were made shortly after the passage of a flood wave into a deep dam reservoir [6, 16, 26]. According to Faithful and Griffiths [4], an influx of highly turbid water may affect processes within the water column; for instance diminishing light penetration and reducing primary production and phytoplankton biomass. In 2007, high concentrations of chlorophyll *a* were observed in the winter (January) in the Dobczyce Reservoir but not at any other time of the year. After the flood wave an insignificant increase of chlorophyll *a* concentration was observed in the upper epilimnion and there was a change in the dominant species among the blue-green algae. However, the development of fast growing species was not observed. It appears that *Woronichinia naegeliana* is a species which may tolerate water mixing. It frequently develops in masses during the autumn overturn and has been causing water blooms in the Dobczyce dam reservoir since 1995 [22], but not every year. It usually forms water blooms in October [23] and sometimes long lasting blooms persist until December [24]. The late summer stormwater in 2007 did not change autumn algal dynamics in the Dobczyce dam reservoir, while the floods in July 1997 changed completely this ecosystem and altered summer algal dynamics [6]. The only similarity of 2007 to other floods (stormwater years) in the Dobczyce dam reservoir was that chlorophyll *a* concentrations after the flood wave passage were higher compared to the previous month. It appears that because this flood wave was close to the regular autumn overturn, it did not cause any significant changes in phytoplankton dynamics or composition.

CONCLUSION

Most of hydrochemical parameters of the Dobczyce Reservoir showed seasonal patterns that are typical of Polish dimictic submountain dam reservoirs. Temperature, pH, and dissolved oxygen were higher in the epilimnion and lower in the hypolimnion, while hydrocarbonate concentrations showed a reverse trend during summer stagnation (except September). The substantial flow through the system in September had a considerable destabilizing effect on the water mass. The reservoir became riverine in nature. Its water chemistry mirrored those of the Raba River. Thus, summer stratification was disturbed and parameters showed no variability (pH) or small variability (temperature, O_2, % O_2) within the water column. In October, there was a return to pH and oxygen stratification in the water column. Stormwater had a diluting effect on the concentrations of salts (sulphate and chloride) in the reservoir water. Conversely, higher concentrations of nutrients were transported through the reservoir. The results obtained indicate that water discharge in the Raba River affects the water transparency, conductivity, chloride, sulphates (negative correlation) concentrations, and P-tot (positive correlation) in the Dobczyce Reservoir. In terms of phytoplankton composition there were notable differences in the dominant species before and after the flood event. While a slight increase of chlorophyll *a* was observed after the flood, chlorophyll *a* was not significantly correlated with water discharge.

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ZMIANY PARAMETRÓW FIZYKOCHEMICZNYCH I FITOPLANKTONU W WODZIE PODGÓRSKIEGO ZBIORNIKA ZAPOROWEGO – WPŁYW LETNIEJ FALI POWODZIOWEJ

Badano zmiany parametrów fizykochemicznych oraz strukturę fitoplanktonu w wodzie dimiktycznego, podgórskiego zbiornika zaporowego (Zbiornik Dobczycki, południowa Polska), przez który we wrześniu przeszła fala powodziowa. Temperatura wody, pH oraz zawartości tlenu rozpuszczonego i wodorowęglanów wykazywały znaczne zróżnicowanie w słupie wody w okresie lata. Fala wezbraniowa płynąca przez zbiornik we wrześniu zaburzyła letnią stratyfikację wykształconą w pelagialu. Spowodowała ona rozcieńczenie stężeń soli (chlorków i siarczanów) oraz niewielki wzrost zawartości azotanów i fosforu ogólnego. Porównując okres przed wezbraniem i krótko po przejściu fali powodziowej, w składzie fitoplanktonu stwierdzono zmiany w obrębie dominujących gatunków należących do sinic (Cyanobacteria).