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Assessment of Phosphorus Retention in the Bottom Sediments of the Solina-Myczkowce Complex of Reservoirs

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1. Introduction

The process of retention pertaining to the phosphorus compounds, taking place in the bottom sediments, consists of three sub-processes: deposition of phosphorus on the surface of the sediments, transformations of phosphorus (mainly organic), and immobilization of phosphorus in the sediments and permanent deposition or penetration within the deeper layers of the sediments. The easier sorption of phosphate ions is, the more Fe, Mn, Al, Ca and organic compounds with a high adsorption capacity is contained in the sediment. Under favorable conditions, should the external load be limited, internal phosphate flux into the overlying water may be initiated (Bartoszek & Tomaszek 2007, Brzozowska et al. 2013, Wisniewski 2007a). Intensity of the exchange of the substances between the aforementioned phases is dependent on the area of contact between them. Under natural conditions, in case of the water ecosystems, the contact areas are enlarged through resuspension of the bottom sediments, the result of which is visible in intensified release of the biogenic substances into the overlaying water, and in increased oxygen consumption during decay processes (Żbikowski 2004). The available research on phosphorus retention in the water body deposits is focused mainly on the "bottom sediment – overlying water" setting. The research is usually carried out with the use of *ex situ* methodology, and sediments with disturbed layers layout were being used to realize that purpose (Hupfer et al.

2000, Jin et al. 2005, Liu et al. 2002). Many of a researchers stated that phosphorus adsorption process in the bottom sediments was tied to the endothermic reactions, as adsorption values were increased proportionally to the temperature (e.g. Hupfer et al. 2000, Jin et al. 2005).

Zero equilibrium phosphate concentration EPC-0 is a very usable measure to assess the bottom sediments, within the scope of adsorption or desorption of phosphate phosphorus, with a defined difference of concentrations between the interstitial water, and overlying water (Wiśniewski 1999). Wiśniewski (1999, 2004 and 2007b), in order to determine the EPC-0 value, utilized a simplified procedure, using a proportion of ca. 40 cubic centimetres of fresh sediment in one litre of the pipeline water. The suspended solids with a variety of phosphate concentrations were undergoing a resuspension process, realized with a magnetic mixer, for 10 minutes, along with re-sedimentation which lasted for 90 minutes.

The aim of the study was to assess the capacity of the bottom sediments of the Solina and Myczkowce complex of dammed reservoirs, within the scope of phosphate retention, on the basis of the *ex situ* research, carried out with regard to the undisturbed cores of the bottom sediments. The bottom sediments constitute an important element of the water ecosystems, mainly due to the problems emerging within the scope of rehabilitation of the degraded reservoirs, connected to the lack of effectiveness of the actions carried out. In order define the equilibrium concentration of the phosphates (EPC-0), a modified methodology was developed, utilizing undisturbed sediment cores. Transferring the *ex situ* experiment results and adapting them for interpretation, extrapolated for the purposes placed within the field research, shall always be realized with caution. However, if the research is based on the sediments that are extracted with disturbance of their natural structure, there is a much higher risk of error than in case of the undisturbed cores.

2. Research area and methodology

Solina reservoir is the largest and the deepest dammed reservoir in Poland (Fig. 1). Along with a smaller Myczkowce reservoir, Solina is a part of the Solina – Myczkowce S.A. Hydropower Plant Complex. Myczkowce acts as a compensation reservoir, acting in support of the pumping power station. San waters coming from the hypolimnion of the Solina

lake constitute the main tributary of the Myczkowce reservoir (more than 90%) (Koszelnik 2013). The catchment area has a mountainous profile, and is not densely populated. The settlements are usually located close to the tributary mouths and in the basin area located directly next to the reservoir. The economic activity within the area is focused mainly on tourism. Solely lumber industry is present within the region. The forested areas dominate the terrain, particularly in the drainage areas of the larger tributaries – Solinka and San (Koszelnik et al. 2008, Koszelnik 2013).

The bottom sediments for the experimental research were extracted at three positions, located within the area of the Solina reservoir and at two stations of the Myczkowce reservoir (Fig. 1). The research was carried out in July and at the beginning of August 2007. Accurately six undisturbed cores of the sediments were extracted from the each site with the use of plexiglass pipes (0-5 cm layer). The pipes were sealed at the bottom with a silicone cap, and then they were transported in a thermally stabilized container to the laboratory. At the lab, the water over the sediment cores was replaced with the reservoir water, diluted (1:4 ratio) with distilled water containing proper content of the phosphate phosphorus (coming in a form of the KH_2PO_4 compound). EPC-0 concentration was determined under the aerobic and anoxic conditions, within the phosphate phosphorus concentrations ranging from 0.0 to 1.3 mg P dm^{-3}. In order to achieve anoxic conditions, once the solutions were prepared, they were depleted of oxygen with the use of anhydrous sodium sulfate (IV) (Wiśniewski 1995, Wiśniewski 2006).

The sediments underwent 10 minutes resuspension, realized through mixing of the surface 1 cm layer, with the use of a mechanical mixer (ca. 150 RPM). According to Panigatti & Maine (2003), phosphorus adsorption takes place in the thin upper layer of the sediment (ca. 1 cm). Assuming that ca. 1 cm of the top layer of the core is going to undergo the mixing process, quantity of the sediment which is going to undergo resuspension constituted ca. 40 cubic centimetres of the sediment in 1 liter of the solution, creating a suspension which is often noted during the presence of intense wind-generated waves in the lake (Wiśniewski 1999, 2004 and 2007b). The containers were sealed off for the mixing period with the Parafilm film (Pechiney, USA) with a small perforated hole in it, allowing the mixing device's elements to rotate. The tests were carried out at the room temperature of ca. 25^{o}C. Next, the reactors were

left aside in a dark and cool place for 110 minutes, in order to allow the suspended solution to re-sediment. After 2 hours long exposure in the over-sediment water, concentration of the phosphate phosphorus (P-PO_4^{3}) was determined. The analysis pertaining to the P-PO_4^{3-} in the water samples was realized with the use of a spectrophotometric method (reaction involving ammonium molybdate) using Aquamate spectrophotometer (Thermo, UK).

Parameter	SR	MR
Area [ha]	2200	200
Max. volume [M m^3]	502	10
Av. (max.) depth [m]	22 (60)	5 (15)
Catchment area [km^2]	1174	1248
Water retention time [d]	215	2-6

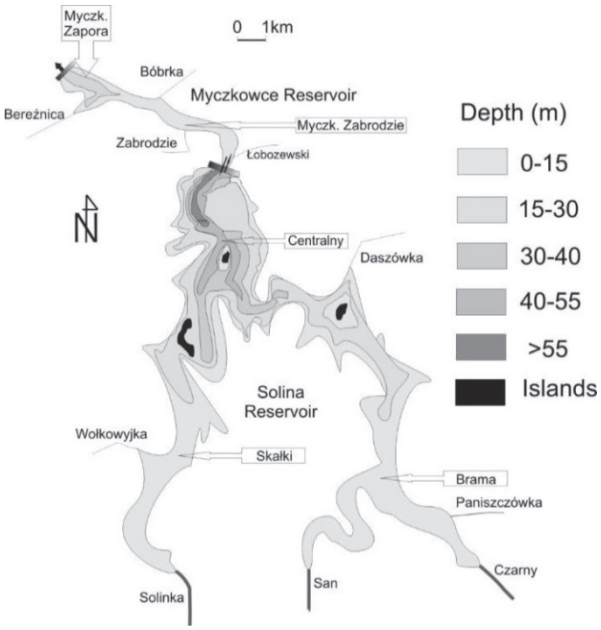

Fig. 1. Locations of the sampling points in the Solina (SR) and Myczkowce (MR) reservoirs and its morphometric parameters
Rys. 1. Rozmieszczenie punktów pobierania osadów dennych w zbiornikach Solina (SR) i Myczkowce (MR) oraz parametry morfometryczne zbiorników

Oxygen and redox potential (Eh) measurements were carried out with the use of a multi-parameter MultiLine P4 meter (WTW Germany), fitted with the CellOx 325 oxygen probe (O_2) and with a combined Sen Tix ORP electrode (Eh). On the basis of the acquired P-PO_4^{3-} concentration data, before and after the 2 hours long exposure, equilibrium phosphate concentration EPC-0 was determined to act as a zero location for the C_p-C_k = f(C_p) linear function, where the parameter values were marked as follows: C_p – initial concentration of the P-PO_4^{3-} before the

exposure, C_k – final concentration of the $P\text{-}PO_4^{3-}$, after 2 h of exposure. In order to interpret the experiment results, results of the research carried out within the period between 2005 and 2006, regarding the water and bottom sediments at the same locations, were utilized. Water and sediment samples were taken 16 times within the period from spring to autumn. $P\text{-}PO_4^{3-}$ and total phosphorus (TP) levels were marked with a spectrophotometric method (TP was determined after the mineralization process in the presence of H_2SO_4 along with peroxodisulfides). TP, Fe, Al and Mn presence in the sediments was analyzed via spectrophotometry after the microwave mineralization procedure was executed (in concentrated HNO_3, at the pressure of 2-4.5 MPa). Ca content values were determined with the use of the AAS technique (Perkin Elmer, AAnalyst 300). The dried sediments were baked at the temperature of 550°C for 4 hours, in order to calculate the organic matter content. Fractionation analysis within the sediments was executed with the use of the SMT method (Pardo et al. 2004, Ruban et al. 2001). The following fractions were obtained: Non-Apatite Inorganic Phosphorus (NAIP, forms bound with oxides and hydroxides of Al, Fe and Mn), Organic Phosphorus (OP) and Apatite Phosphorus (AP, Ca-bound form).

3. Results and Discussion

During the experimental research under the aerobic conditions, it turned out that the best retention properties were recorded in case of the sediments coming from Myczk. Zapora, and Skałki locations, and insignificantly worse from the Brama and Centralny locations. The worst retention properties had sample came from the Myczk. Zabrodzie sampling point (Fig. 2 and 3). Deposits coming from the Myczk. Zapora and Skałki locations did not differ significantly within the scope of Al, Ca, Fe, Mn and AP fraction content (Table 1), which was confirmed by the variance analysis (ANOVA; $p < 0.05$) of the mean content of the parameters examined in the sediments within the period between 2005 and 2006 (Bartoszek et al. 2015). Insignificantly weaker retention within the sediments at the Centralny station could have been caused by the lower calcium content, despite the higher content of the remaining substances mentioned above.

Much smaller phosphorus retention capacity was shown by the sandy deposits of the Myczk. Zabrodzie location – this was related to much lower Fe, Mn and Al content, as well as to the lower value of the Fe/P ratio (ca. 25), which means that the binding between the phosphorus and the above-mentioned elements was weaker. Low retention capacity of the sediments from the aforementioned location could also have been caused by the limited quantity of the organic matter, which had an impact on the OP fraction content, as well as on the NAIP content, within the deposits. Humic acids, along with iron, cause the phosphorus to be immobilized in a form of non-mobile humus – iron – phosphorus compounds (Kentzer 2001).The remaining metals – Al, Mn, Ca – are also capable of creating complex compounds with the organic matter and phosphorus, within the sediments (Darke & Walbridge 2000). Under anoxic conditions, higher retention values were observed for the sediments at the Centralny location and Myczk. Zapora, while phosphorus retention was the weakest in case of the Skałki location deposits (Figs 2 and 3). In the sediment from the Brama and Myczk. Zabrodzie locations, phosphorus retention under anoxic conditions were weaker. A large excess of Fe and Mn in the deposits makes it possible to stabilize the connection between the phosphorus and these elements, when the redox potential value is low.

Phosphorus may be durable binded by iron (III) oxides and hydroxides. This durability is indicated by high values of the Fe/P ratio in case of the bottom sediments of the analyzed water bodies, within the period between 2005 and 2006 (on average: 52.4 for Solina and 41.5 for Myczk. Zapora). The lacustrine zones of the reservoirs usually feature the sediment with a more fine grain, in comparison with the areas of the river inflow. Exchange of phosphorus in the water – sediment interface is also dependent on contribution of the fine particles of the sediment which – for a longer period of time – remain in the suspension, once the resuspension process occurs (Wiśniewski 1995).

The sediments of the Brama location were very atypical, well consolidated and viscous, this could have contributed to their varied appearance. The lowest Eh value (97.1 mV) could be attributed to the solutions, during the tests related to the sediments coming from the abovementioned location.

Table 1. Average values of the selected parameters and contribution of the phosphorus fraction in the total quantity of phosphorus in the bottom sediments of the Solina and Myczkowce reservoirs, within the period between 2005 and 2006
Tabela 1. Średnie wartości wybranych parametrów i udział frakcji fosforu w fosforze całkowitym w osadach dennych zbiorników zaporowych Solina i Myczkowce w latach 2005-2006

Station / Parameter		Centralny	Brama	Skałki	Myczk. Zapora	Myczk. Zabrodzie
$P_{tot.}$	[mg g^{-1} of d.w.]	0.91 ± 0.05	0.86 ± 0.05	0.69 ± 0.02	0.87 ± 0.08	0.62 ± 0.04
Fe		44.6 ± 5.7	43.3 ± 2.7	39.8 ± 2.5	35.9 ± 2.9	15.6 ± 3.5
Mn		2.82 ± 1.1	2.10 ± 0.5	1.66 ± 0.3	1.37 ± 0.3	0.58 ± 0.3
Al		40.5 ± 4.5	38.9 ± 5.0	35.8 ± 2.6	34.1 ± 4.1	16.4 ± 3.6
Ca		7.67 ± 1.5	12.0 ± 3.3	14.2 ± 3.4	12.9 ± 6.2	27.1 ± 7.5
Fe/P		49.0 ± 6.1	50.6 ± 2.4	57.8 ± 4.5	41.5 ± 4.4	25.2 ± 3.6
OM	[%]	8.86 ± 0.6	8.81 ± 0.6	8.19 ± 0.5	11.5 ± 2.5	2.79 ± 1.9
NAIP		26.0 ± 3.0	22.9 ± 2.4	18.3 ± 3.2	29.6 ± 3.3	21.0 ± 2.6
OP		35.2 ± 3.6	34.0 ± 1.9	31.7 ± 2.5	33.1 ± 2.5	23.0 ± 2.5
AP		35.2 ± 5.3	39.7 ± 3.8	44.5 ± 3.1	34.0 ± 2.4	51.6 ± 3.5
W_o		68.6 ± 6.7	64.5 ± 3.9	58.9 ± 1.7	68.6 ± 6.9	42.1 ± 2.4

This also had an impact on maintaining the bonds with phosphorus under anoxic conditions. Hence, the phosphorus retention in case of the deposits collected at that location could have been harder, due to the atypical structure of the sediment and the lowest redox potential in case of the solution, which also could have been a reason for achieving one of the higher EPC-0 values under anoxic conditions (Table 2). The bottom sediments, in case of the dammed reservoirs, were characterized by very low EPC-0 values in the oxygenated conditions. Oxygen concentrations above the sediments ranged – before the exposure – within the scope between 6.52 and 7.61 mg O_2 dm^{-3}, while after the exposure was completed, the values ranged between 3.9 and 5.05 mg O_2 dm^{-3}. The lowest EPC-0 value was recorded for the sediments at the Brama location (0.007 mg P dm^{-3}), the highest was reached at the Centralny (0.057 mg P dm^{-3}). The obtained EPC-0 values for the remaining deposits were very close to one another. The value of the P-PO_4^{3-} EPC-0 concentration suggests that releasing of the phosphates to the overlying water may be expected, once the phosphate phosphorus concentration is lower than the above-mentioned value.

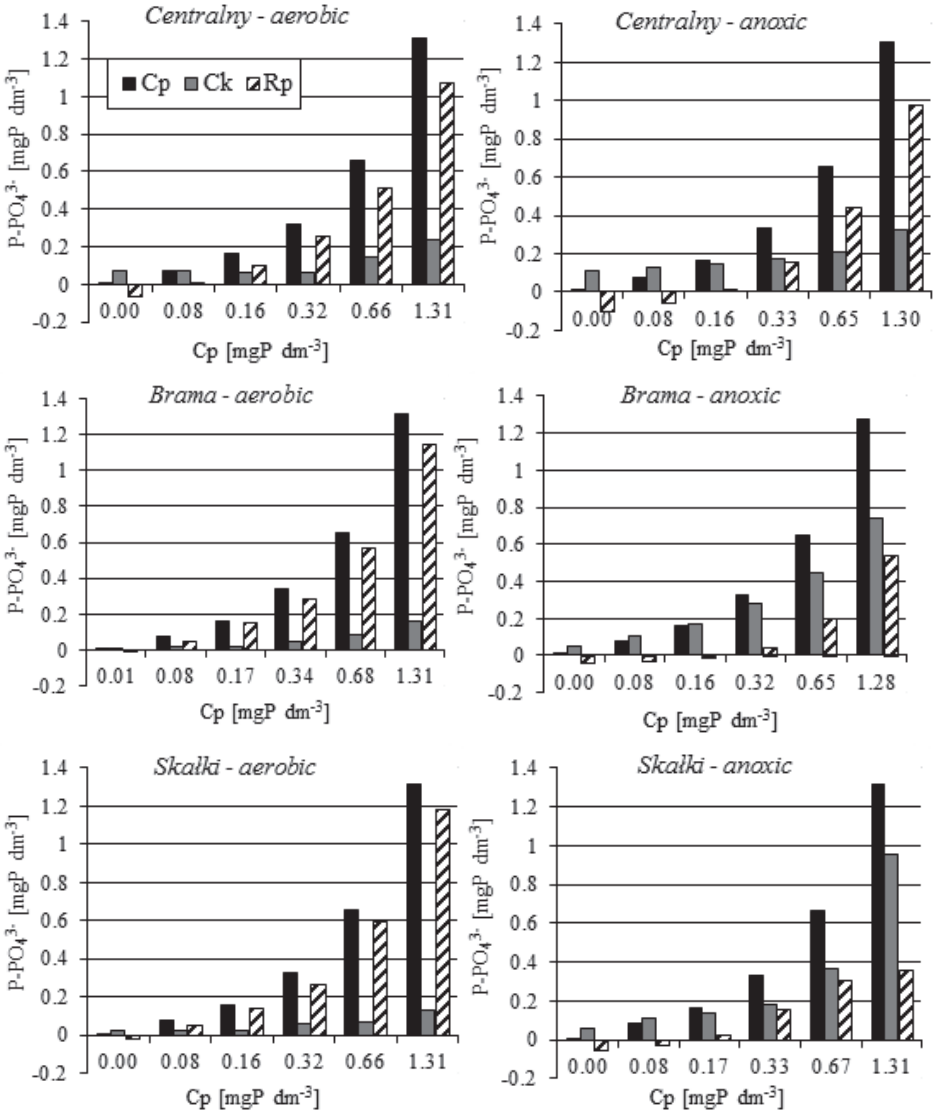

Fig. 2. Retention of phosphate phosphorus (R_P) [mg P dm^{-3}] in the bottom sediments of the Solina reservoir, after 2 hours long exposure in aerobic and anoxic conditions

Rys. 2. Retencja fosforu fosforanowego (R_P) [mg P dm^{-3}] w osadach dennych zbiornika Solina po 2 h ekspozycji w warunkach aerobowych i anoksycznych

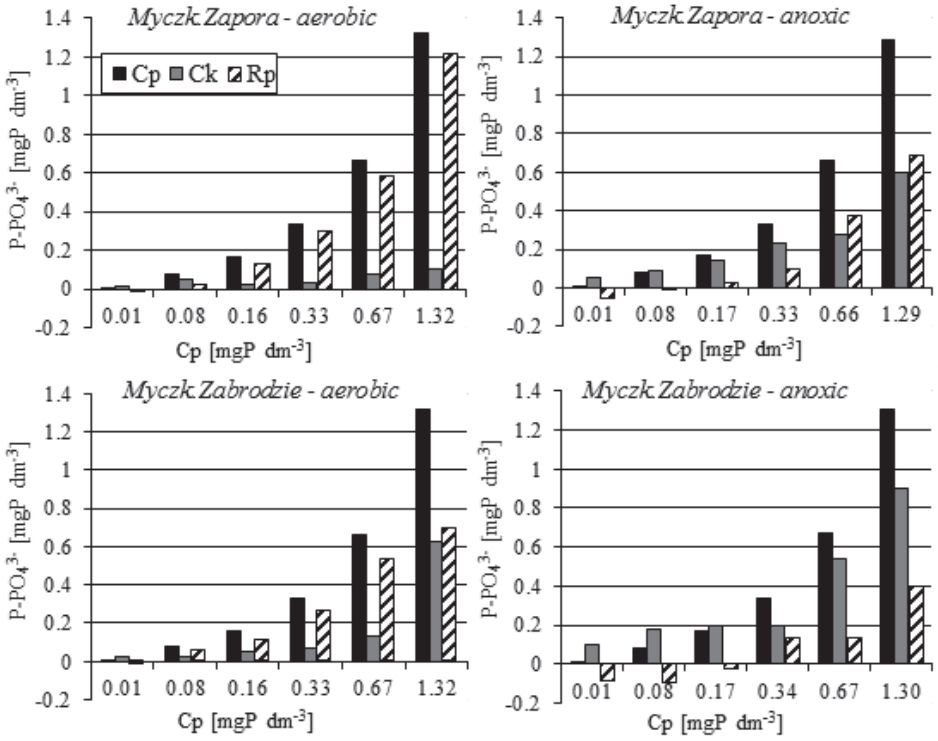

Fig. 3. Retention of phosphate phosphorus (R_P) [mg P dm^{-3}] in the bottom sediments of the Myczkowce reservoir, after 2 hours long exposure in aerobic and anoxic conditions

Rys. 3. Retencja fosforu fosforanowego (R_P) [mg P dm^{-3}] w osadach dennych zbiornika Myczkowce po 2 h ekspozycji w warunkach aerobowych I anoksycznych

However, adsorption of $P\text{-}PO_4^{3-}$ may be expected, once the phosphate phosphorus concentration in the overlying water exceeds the EPC-0 value (House 2003). Within the period between 2005 and 2006 no values of $P\text{-}PO_4^{3-}$ concentration lower than the EPC-0 value were recorded, however this only applies to the case of the Brama location (Table 3).

The remaining locations (particularly the Centralny one) insignificantly lower mineral phosphorus concentrations were observed. Theoretically – to a minor degree – the release process pertaining to the phosphates could have been occurring, leading to the process in which the

concentrations between the interstitial waters and the water layer above the bottom was being balanced. The total phosphorus concentration, particularly in the overlying water of the Solina reservoir, was much higher, as a large contribution of the organic and suspended forms was present.

Table 2. The determined EPC-0 values [mg P dm^{-3}] for the bottom sediments of the Solina and Myczkowce reservoirs (r – correlation coefficient)
Tabela 2. Wyznaczone wartości równowagowego stężenia fosforanów EPC-0 [mg P dm^{-3}] dla osadów dennych zbiorników zaporowych Solina i Myczkowce (r – współczynnik korelacji)

Station	Aerobic conditions			Anoxic conditions		
	EPC-0 [mg P dm^{-3}]	r	n	EPC-0 [mg P dm^{-3}]	r	n
Centralny	0.057	0.999	6	0.140	1.000	6
Brama	0.007	1.000	6	0.169	0.993	6
Skałki	0.020	1.000	6	0.106	0.994	5
Myczk. Zapora	0.026	0.999	6	0.103	0.995	6
Myczk. Zabrodzie	0.021	1.000	5	0.274	0.997	5

This shows that even despite the fact that the concentration of the mineral form of phosphorus was low, the processes of depositing outweighed the potential release. Particularly due to the fact that water in the area close to the bottom of the Solina reservoir, on the dates when the samples were drawn, throughout the whole period of the research (2005-2006) has shown quite good oxygenation parameters (> 4 mgO_2 dm^{-3}). During the research carried out in the anoxic conditions, oxygen concentrations in the solutions above the sediments, before the exposure, ranged from 0.01 to 0.03 mg O_2 dm^{-3}, and these levels were maintained through ca. 2 hours of exposure. As the oxygen content is lowered, redox potential is also lowered in the overlying water. Redox potential measurements (Eh), due to the prolonged value stabilization periods, initially were carried out solely for prepared, de-oxygenated initial solutions. The obtained Eh values were contained within a range between 97.1 and 136.4 mV. In the anoxic conditions, higher values of the EPC-0 parameter were achieved. The highest EPC-0 value was achieved for the samples from the Myczk. Zabrodzie (0.274 mg P dm^{-3}), while the lowest values were recorded at the Myczk. Zapora (0.103 mg P dm^{-3}) and Skałki (0.106 mg

P dm^{-3}). Exchange of the substances between the bottom sediments and overlying water is largely dependent on the oxidation – reduction conditions present on the thin upper layer of the deposits. Compounds of phosphorus with iron and manganese and organic derivatives dependent on changes in the redox potential are all responsible for increased release in the oxygen deficit conditions.

Table 3. Concentrations of the phosphate and total phosphorus concentrations in the waters of the Solina and Myczkowce reservoirs, within the period between 2005 and 2006 (sw – surface waters, ow – overlying water)
Tabela 3. Stężenia fosforu fosforanowego i całkowitego w wodzie zbiorników zaporowych Solina i Myczkowce w latach 2005-2006 (sw – woda powierzchniowa, ow – woda naddenna)

Station	Centralny		Brama		Skałki		Myczk. Zabr.	
	sw	ow	sw	ow	sw	ow	sw	ow
$P\text{-}PO_4^{3-}$ [mg P dm^{-3}]								
Mean	0.03	0.04	0.03	0.05	0.03	0.04	0.05	0.05
Minim.	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01
Max	0.09	0.07	0.09	0.12	0.07	0.11	0.12	0.15
Std. Dev.	0.02	0.02	0.02	0.03	0.02	0.03	0.03	0.05
TP [mg P dm^{-3}]								
Mean	0.06	0.14	0.08	0.16	0.07	0.11	0.11	0.12
Minim.	0.02	0.05	0.03	0.08	0.02	0.05	0.02	0.04
Max	0.12	0.29	0.19	0.28	0.14	0.26	0.29	0.28
Std. Dev.	0.03	0.08	0.04	0.07	0.04	0.05	0.07	0.07

The reason for presence of the varied values of the EPC-0 parameter for the bottom sediments in the examined reservoirs was searched for through analysis of the chemical composition and content of the phosphorus fraction results, obtained throughout the research carried out in the recent years. The EPC-0 values from the Centralny and Skałki locations could have been influenced by the total phosphorus and mobile fractions (NAIP + OP) values, higher within the sediments of the lacus-

trine zone (Centralny) and lower in case of the riverine zone (Skałki). In the Myczkowce reservoir, higher EPC-0 value in aerobic conditions was recorded for the deposits from the Myczk. Zapora location. In case of these sites, higher total phosphorus content was visible, along with higher concentrations of the NAIP and OP fraction, especially in comparison with the Myczk. Zabrodzie location. Despite the lower phosphorus and mobile fractions content, maximum EPC-0 value for anoxic conditions was present in case of the sandy sediments of the shallow littoral zone of the Myczk. Zabrodzie location. Lower durability of the phosphorus compounds in these conditions must have resulted from lower iron, manganese (2 times less) and organic matter (4 times less) contents in the bottom sediment (Table 1).

The analysis of the impact of the selected parameters on the EPC value has shown that there is a statistically significant negative correlation between the EPC-0 and content of the organic matter in the anoxic conditions ($r = -0.908$; $p < 0.05$). Increased EPC-0 value, along with decreased organic matter content, confirms the fact that creation of immobile complex connections formed by phosphorus and humus compounds and metals, is a significant mechanism of phosphorus retention in typically mineral sediments of the reservoirs. Humus substances constitute up to 80% of the general quantity of the organic substances contained in the sediments (van Loon & Duffy 2007). Moreover, significant correlation were observed for the negative relationships between the average content of the Fe, Al, Fe/P ratio, and EPC-0, in anoxic conditions ($r = -0.796$, $r = -0.811$; $r = -0.800$ respectively). However, these relationships were not statistically significant ($p > 0.05$).

On the basis of the data derived from the literature (Table 4) it was noted that the phosphorus content in the sediments of some other water bodies had a statistically significant ($r = 0.765$; $p < 0.05$) impact on the obtained EPC-0 values in the aerobic conditions. In case of the research presented in the work, no statistically significant correlation was confirmed, neither for aerobic, nor for the anoxic conditions. Low quantity of the recorded EPC-0 values (5 for the given conditions), including one for sandy littoral sediments (a separate type) does not ultimately exclude presence of such relationship. Borovec & Hejzlar (2001) did not discover any relationship between aerobic EPC-0 and the chemical composition of the benthic sediments (including sediments with phosphorus)

of the European lakes and reservoirs. Cyr et al. (2009) also did not observe the relationship between the aerobic EPC-0 parameter and the chemical composition in the littoral zone sediments.

Similarly low total phosphorus content (0.3-0.6 mg g^{-1}) and dominating presence of the apatite fraction (Ca-P > 70%) were recorded in case of the littoral sediments of the German lake. Despite the fact that the mobile fraction constituted a minor (< 3%) part of the total phosphorus, littoral, sandy deposits were considered to be a significant source for release of phosphorus during the summer season (Güde et al. 2000). According to Andersen & Ring (1999), the littoral sediments of the shallow, eutrophic lakes, may make a significant contribution to the load imposed on the water with the phosphorus substance, in comparison with the benthic sediments, especially in cases when oxygen concentration is low at the boundary between the sediment and overlying water. Cyr et al. (2009) achieved low values of the EPC-0 parameter in aerobic conditions (up to 0.005 mg P dm^{-3}) for the littoral sediments in the Opeongo lake, however in conditions when resuspension was quite common, the researchers assumed that they may be a real source of phosphorus for the littoral plants.

Table 4. EPC-0 values determined for the bottom sediments of other water reservoirs (aerobic conditions, distorted layering)
Tabela 4. Równowagowe stężenia fosforanów EPC-0 wyznaczone dla osadów dennych innych zbiorników wodnych (warunki aerobowe, osady o zaburzonym uwarstwieniu)

Reservoir	EPC-0 [mgP dm^{-3}]	$P_{tot.}$ [mgP g^{-1} d.w.]	Reference
Arendsee lake	0.137	0.203	Hupfer et al. 2000
East Taihu lake Wuli lake	0.02 0.157	0.451 0.819	Jin et al. 2005
Loch Leven lake	0.008-0.021	2.3	Spears et al. 2006
Łasińskie lake	0.942 0.239	– –	Wiśniewski 1999
Jelonek lake	0.109 0.209	1.95 2.24	Wiśniewski 2006
Winiary lake	0.544 0.209	2.97 1.65	Wiśniewski 2007b

Both in case of the oxygenated, as well as in case of the anoxic conditions, phosphates are released from the eutrophic reservoirs' bottom sediments, however, release in oxygen-less conditions is more intensive (Selig 2003) and this was also confirmed by the research carried out. The capacity to release of phosphates out of the sediments, should an oxygen deficit occur in the overlying water, is better replicated by the EPC-0 value determined in the anoxic conditions.

Low EPC-0 values, low complete phosphorus and organic matter content in the deposits, altogether suggest that the bottom sediments of the Solina and Myczkowce reservoirs (excluding the sandy littoral deposits) are still at the first stage of trophic development, in conditions favourable for retention of the phosphorus compounds.

5. Conclusions

During resuspension of the sediments in the water body, release, as well as retention of the phosphates may both take place. The process type is, above all, dependent on concentration of the phosphates in the overlying water and on content of the parameters (Fe, Al, Mn, Ca, and OM) increasing the retention capabilities pertaining the sediments in the given oxidation – reduction conditions.

The sediments, in the examined reservoirs (excluding the sandy littoral deposits) turned out to have a great phosphorus retention capacity, especially under aerobic conditions. Phosphorus retention, under anoxic conditions, was less intense within the sediments of both reservoirs. Sediments sampled at the compensation reservoir turned out to be the most varied ones, within the scope of the retention capacity. Despite the lower iron, aluminum and manganese content, in comparison with the Solina reservoir, the Myczkowce lacustrine zone sediment (Myczk. Zapora) has shown the highest level of the phosphorus retention capabilities. This could have been connected with the highest organic matter content, which leads to emergence of hardly soluble complexes with metal ions, e.g. iron – phosphorus – humus.

The sandy littoral deposits, even though the total phosphorus, mobile fractions and organic matter contents were lower, turned out to be in possession of the highest capacity to release the phosphates in anoxic conditions (the highest value of EPC-0). At the same time, the phospho-

rus retention capacity was insignificant. In favourable conditions – higher water temperature, along with the lowered redox potential – may lead to release of the phosphorus from this type of sediments in case of both reservoirs.

In case of the Solina – Myczkowce reservoirs, phosphorus deposition in the bottom sediments outweighed the processes of release. This is proven mainly by the low capacity to release the phosphates, and high level of retention capacity in most of the sediments. Additionally the total phosphorus, mobile fractions and organic matter content is relatively low. Same situation is present when it comes to the mineral form of the total phosphorus, in the overlying water.

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Ocena retencji fosforu w osadach dennych zespołu zbiorników zaporowych Solina-Myczkowce

Streszczenie

Przeprowadzono badania *ex situ* w warunkach aerobowych i anoksycznych na niezaburzonych rdzeniach osadów dennych zbiorników zaporowych Solina i Myczkowce w celu oceny ich zdolności do retencji fosforanów. Osady badanych zbiorników (za wyjątkiem piaszczystych depozytów litoralnych) wykazały się bardzo dużą zdolnością zatrzymywania fosforu, zwłaszcza w warunkach aerobowych. Retencja fosforu w warunkach anoksycznych zachodziła w osadach obu zbiorników mniej intensywnie. Piaszczyste osady litoralne, pomimo niższych zawartości fosforu całkowitego, frakcji mobilnych oraz materii organicznej, wykazały najwyższą zdolność wydzielania fosforanów

w warunkach anoksycznych (najwyższa wartość równowagowego stężenia fosforanów w punkcie zero EPC-0) i nieznaczne tylko zdolności do zatrzymywania fosforu. W zbiornikach zaporowych Solina i Myczkowce procesy depozycji fosforu w osadach dennych przeważały nad procesami jego uwalniania. Świadczy o tym głównie niska zdolność uwalniania fosforanów i wysoka zdolność retencyjna przeważającej partii osadów.

Abstract

Ex situ research was carried out under aerobic and anoxic conditions, pertaining to the undisturbed cores of the bottom sediments within the Solina and Myczkowce complex of dammed reservoirs, within the scope of assessing their capacities related to retention of phosphates. The sediments, in the examined reservoirs (excluding the sandy littoral deposits) turned out to have a great phosphorus retention capacity, especially under aerobic conditions. Phosphorus retention, under anoxic conditions, was less intense within the sediments of both reservoirs. The sandy littoral deposits, even though the total phosphorus, mobile fractions and organic matter contents were lower, turned out to be in possession of the highest capacity to release the phosphates under anoxic conditions (the highest value of zero equilibrium phosphate concentration EPC-0). At the same time, the capacity of phosphorus retention was insignificant. In case of the Solina and Myczkowce reservoirs, phosphorus deposition in bottom sediments outweighed the processes of phosphorus release. This is proven mainly by the low capacity to release the phosphates, and high level of retention capacity in most of the sediments.

Słowa kluczowe:
zbiorniki zaporowe, osady denne, retencja fosforanów,
równowagowe stężenie fosforanów (EPC-0)

Keywords:
reservoirs, bottom sediments, phosphates retention,
zero equilibrium phosphate concentration (EPC-0)