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*Short communications*

**CHEMICAL COMPOSITION OF THE SURFICIAL  
SEDIMENTS IN LAKE LICHEŃSKIE**

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ABSTRACT. The study revealed that the surficial sediments of Lake Licheńskie were mineral with a low organic matter content. The main components of the chemical composition were calcium carbonate and silica. Phosphorus in the surficial sediments occurred in small amounts not exceeding 2 mg P g<sup>-1</sup> d.w. Higher values (maximum to 6.232 mg P g<sup>-1</sup> d.w.) were observed only in the outlet zone of the Licheński Canal that carries post-cooling water into the lake. The majority of sediment phosphorus was of fractions that are nearly insoluble residual P (res-P) and those that are moderately soluble (NaOH-P) and difficult to dissolve (HCl-P), which means that phosphorus is more or less permanently bound in the surficial sediments. The Lake Licheńskie sediments will remain a phosphorus trap under the condition that the pollution load from the catchment basin is limited.

Key words: LAKE, SURFICIAL SEDIMENTS, PHOSPHORUS FRACTION

Surficial sediments are one of the most important elements in lake ecosystems. They usually act as a storehouse for both allochthonous and autochthonous material. The geological character of the lake's catchment area, how it is exploited, the morphometrics of the lake basin, and hydrological relationships have the most significant impacts on the types of sediments deposited (Kentzer 2001). The compounds stored in the sediments can be re-released into the water column under the appropriate conditions. A range of factors impact this, among which the most influential are near-bottom water temperature and oxygen content (Cercó 1989, Suplee and Cotner 2002). The release of stored nutrients, especially phosphorus, from the surficial sediments can have a significant impact on the trophic state of basins (Zdanowski et al. 2002). Detailed knowledge of the amount of bioavailable phosphorus

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permits evaluating its role as a source of internal loading. The most mobile phosphorus fraction is  $\text{NH}_4\text{Cl-P}$ , which is loosely bound to the sediments, and iron-bound phosphorus (BD-P) that is susceptible to changes in redox potential. The  $\text{NaOH-P}$  fraction, phosphorus bound to aluminum hydroxide and iron and organic matter, is regarded as much less mobile (Rydin 2000). While the  $\text{HCl-P}$  fraction of calcium-bound phosphorus is less bioavailable, and the  $\text{res-P}$  fraction is permanently bound to the sediments (Psenner et al. 1988, Kentzer 2001).

The aim of the study was to determine the chemical composition of the surficial sediments of Lake Licheńskie with a particular focus on the components shaping their capacity for retaining phosphorus. Surficial sediments are a valuable source of information on the eutrophication rates of lakes. Knowledge of this element of the ecosystem permits planning protective measures and restoring basins.

Lake Licheńskie has a surface area of 147.6 ha with a maximum depth of 12.6 m and a mean of 4.5 m. It is trough-shaped, and has a highly developed shoreline. A discharge canal runs along its southeastern shore and is separated from the lake by an earthen dike. Lake Licheńskie is connected to a power plant cooling system throughout the year and receives the main flow of the post-cooling waters. The discharge of water into the lake is unconstrained, which causes it to mix with lake waters in the surface layer thus forming horizontal temperature gradients. Lake Licheńskie is a mictic lake with a tendency to be polymictic. The northern and southern parts receive waters that are less heated, so during colder winters these areas can be covered by a thin layer of ice (Socha and Zdanowski 2001).

Sediment samples 5 cm thick were collected in July 2005 with a Kajak sediment core sampler at three study profiles (Fig. 1). Profile P was located near the Licheński Canal post-cooling water outlet. Profile B was located about 1100 m to the south of Profile P. Profile S was located on the opposite shore of the lake and included the deepest part of the lake. Sediments were collected from each profile from various depth zones (littoral 0.5-1.5 m, sublittoral 4-5 m, profundal 6-11 m).

The method by Januszkiewicz (1978) was used to determine the hydration and dry weight of fresh sediments. The sediment phosphorus fraction was determined in fresh sediments using the method proposed by Psenner et al. (1988). After drying at room temperature, the remaining sediments were pulverized in a porcelain mortar and subsamples were taken to perform the various determinations. The sediment content of

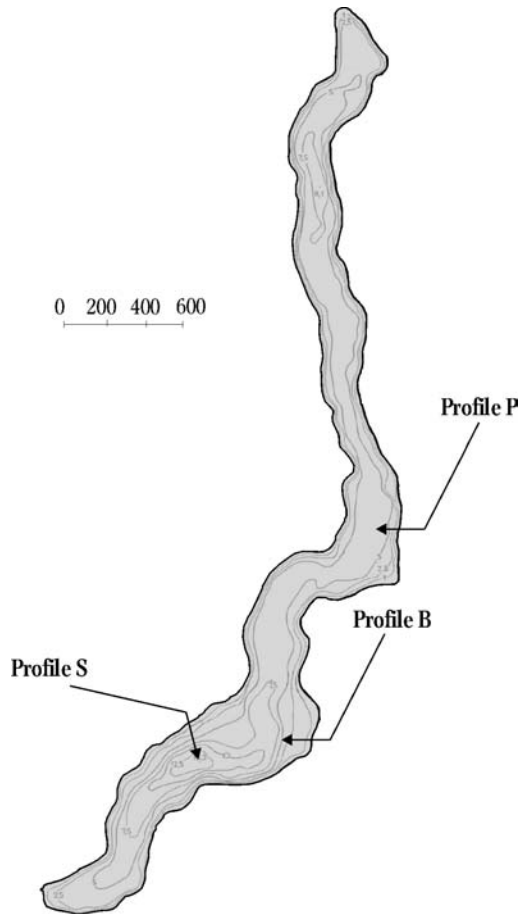


Fig. 1. Map of Lake Licheńskie with the bottom sediment stations.

organic materials and carbonates were determined by weight after regeneration with carbon dioxide, while the contents of silica, iron, calcium, aluminate, magnesium, manganese, total nitrogen, and phosphorus were determined using methods by Januszkiewicz (1978).

The surficial sediments of Lake Licheńskie differed in both the degree of hydration and chemical composition. The lowest degree of hydration was noted in the littoral zone sediments taken from a depth of 0.5 m (21.45 and 29.42%, respectively at stations P0.5 and B0.5; Fig. 2). The highest water content was noted in sediments from site P6 (91.35%; Fig. 2a). Generally, sediment hydration increased along with the depth of the sampling site.

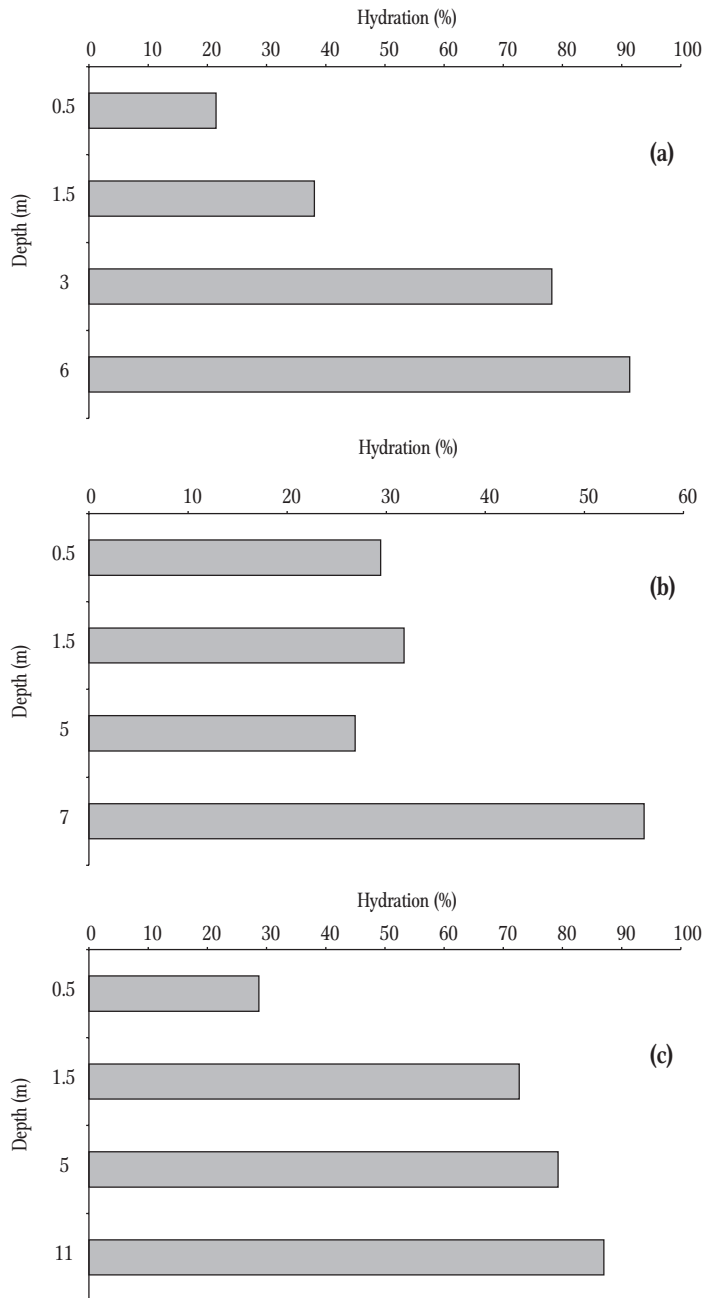


Fig. 2. Hydration of surficial sediments in Lake Licheńskie: Profile P (a), Profile B (b), Profile S (c).

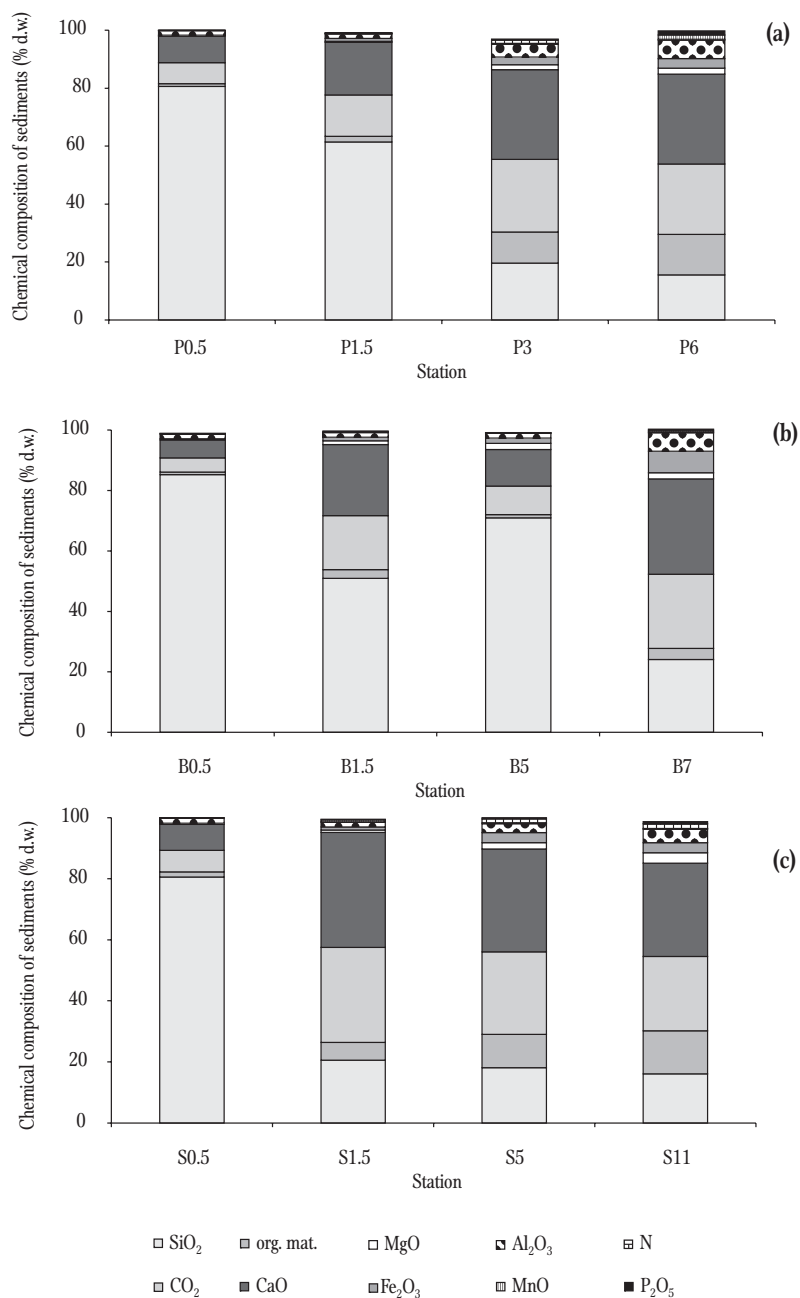


Fig. 3. Chemical composition of the surficial sediments (% dry weight) of Lake Licheńskie: Profile P (a), Profile B (b), Profile S (c).

This was not noted at Profile B (Fig. 2b), and could be linked to the fact that the only factor shaping the surficial sediment structure in Lake Licheńskie was hydrological conditions. This was reflected in the chemical composition of the surficial sediments, the variation of which did not increase in the sediments from Profile B (Fig. 3).

The main components of the chemical composition of Lake Licheńskie sediments were calcium carbonate and silica. The mineral character of the lake's sediments affected this. The calcium content fluctuated from 5.97% (B0.5) to 37.68% CaO d.w. (S1.5), while the quantity of carbonates ranged from 4.69% (B0.5) to 31.09% CO<sub>2</sub> d.w. (S1.5) (Fig. 3). A statistically significant positive correlation was determined between the two components ( $r = 0.981$ ,  $N = 12$ ,  $P = 0.01$ ), which indicates that calcium was deposited primarily as CaCO<sub>3</sub>. The calcium carbonate type of water in Lake Licheńskie and the alkalization of the environment ( $\text{pH} > 8.3$ ) are advantageous for the biological decalcification of the water. The contents of calcium and carbonates in the surficial sediments of Lake Licheńskie are high in comparison with those reported for other lakes (Brzozowska et al. 2005). Rutkowski (2004) noted higher levels of calcium carbonate in the sediments from Lake Wigry (even exceeding 90% CaCO<sub>3</sub>).

The levels of silica noted in the surficial sediments of Lake Licheńskie ranged from 15.54% (P6) to more than 85% SiO<sub>2</sub> d.w. (B0.5). The sediments sampled from a depth of 0.5 m in the littoral zones at all the profiles were the richest in this component, which was determined to be average. In Lake Dejugny, the range was between 45 to 95% SiO<sub>2</sub> d.w. (Brzozowska et al. 2005).

Organic matter was the third most abundant component of the Lake Licheńskie sediments, the quantity of which ranged from 0.83% (B0.5) to 14.05% d.w. (S11) (Fig. 3). This is a small quantity in comparison to that in the sediments of many other lakes (Kentzer 2001, Gawrońska et al. 2003). The change in thermal regime could have had an impact on this. Near-bottom water temperature at Profiles P and B during sampling exceeded 22°C, while at the deepest sites in the lake (S11) it was 14°C (Table 1).

The quantity of organic material in the surficial sediments of lakes determines the sediment nitrogen content, which is because the nitrogen deposited in sediments is primarily in the organic form (Zdanowski 1983). This was confirmed in Lake Licheńskie by the small quantity of nitrogen (from 0.06% to 1.60% N d.w.) (Fig. 3) as well as the strict correlation between the content of organic matter and nitrogen ( $r = 0.995$ ,  $N = 12$ ,  $P = 0.01$ ).

TABLE 1

Temperature and dissolved oxygen content of near-bottom water in Lake Licheńskie at the study sites

Profile P			Profile B			Profile S		
Site	Temperature (°C)	Oxygen (mg O <sub>2</sub> dm <sup>-1</sup> )	Site	Temperature (°C)	Oxygen (mg O <sub>2</sub> dm <sup>-1</sup> )	Site	Temperature (°C)	Oxygen (mg O <sub>2</sub> dm <sup>-1</sup> )
P0.5	27.6	8.10	B0.5	27.0	9.60	S0.5	27.6	9.42
P1.5	26.7	6.46	B1.5	27.0	9.27	S1.5	26.8	8.55
P3	25.2	4.83	B5	24.3	4.20	S5	24.2	4.35
P6	23.4	3.60	B7	22.8	0.69	S11	14.0	0.00

According to the Stangenberg (1938) classification, the littoral sediments of Lake Licheńskie are of the silica type, while those from deeper parts of the lake are calcareous. The quantities of the other mineral components of Lake Licheńskie surficial sediments did not exceed several percent of the dry weight (Fig. 3). Manganese occurred in the sediments of the studied lake in small quantities that did not exceed 0.35% MnO d.w. Similarly, magnesium content was low (up to 3.41% MgO d.w. (S11)), while that of aluminum and iron were average (up to 6.43% Al<sub>2</sub>O<sub>3</sub> d.w. (P6) and to 7.15% Fe<sub>2</sub>O<sub>3</sub> d.w. (B7)), in comparison to the quantities occurring on the sediments of other lakes (Brzozowska et al. 2005).

The most important component with regard to eutrophication is phosphorus (Søndergaard et al. 1996, Brzozowska and Gawrońska 2005). The phosphorus compounds deposited in surficial sediments can be released into the water over the course of many years thus supporting primary production. The phosphorus sorption capabilities of surficial sediments depends mainly on the content of iron, manganese, and aluminum, and to a lesser extent on calcium (Golterman 1988, 1998). This is linked to the bioavailability of phosphorus depending on the varied mobility of this element when bound to the various elements occurring in the sediments.

The content of NH<sub>4</sub>Cl-P, the most mobile fraction, confirmed in the surficial sediments of Lake Licheńskie was not great and reached a maximum value of 0.074 mg P g<sup>-1</sup> d.w. (P6) (Fig. 4). The quantity of the BD-P fraction (susceptible to changes in redox potential) were also low and ranged from 0.017 (B5) to 0.293 mg P g<sup>-1</sup> d.w. (P6). Potentially, this indicates that there is a small quantity of sediment phosphorus that is most readily able to return to the cycle in the lake. A similar quantity of this phosphorus fraction was noted by Kentzer (2001) in lakes with various trophic status. Slightly

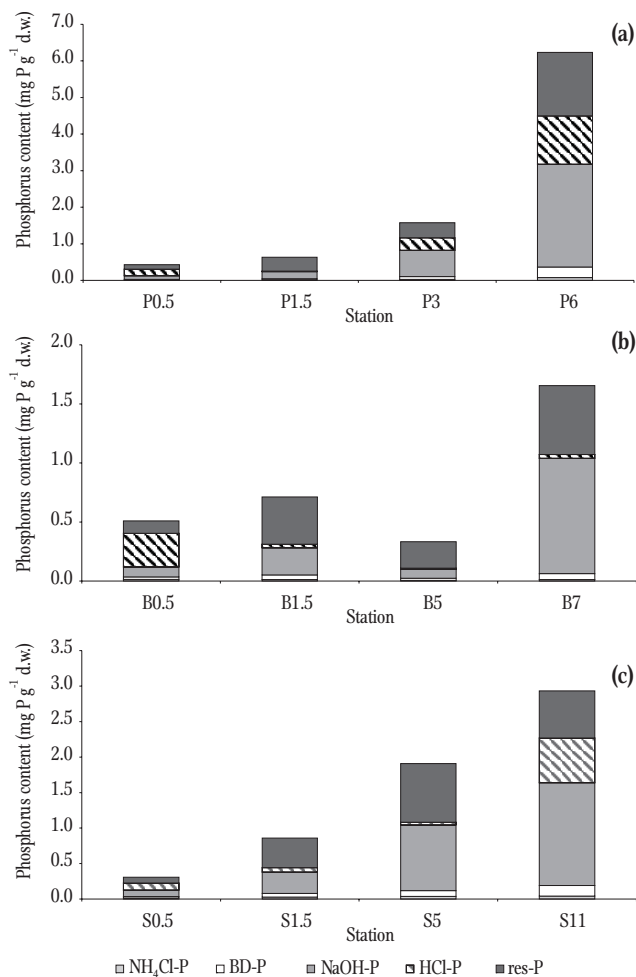


Fig. 4. Content of phosphorus fractions in the sediments of Lake Licheńskie: Profile P (a), Profile B (b), Profile S (c).

higher quantities of NH<sub>4</sub>Cl-P and BD-P were observed by Kowalczevska-Madura et al. (2005) in the sediments of the nutrient overloaded Lake Swarzędzkie.

The quantity of calcium-bound phosphorus (HCl-P) ranged from 0.010 (B5) to 1.328 mg P g<sup>-1</sup> d.w. (P6). This dominated mainly in samples taken from depths of 0.5 m (B0.5). Despite the high content of CaCO<sub>3</sub> in the surficial sediments of Lake Licheńskie, no statistically significant correlation was determined between calcium content in the sediments and the quantity of the HCl-P fraction. Gonsiorczyk et. al.



(1998) also noted the lack of similar dependencies in German hard water lakes. In the opinion of Golterman (1988), lakes with high  $\text{CaCO}_3$  content in the sediments (10-30%) and in the presence of even small quantities of iron hydroxide phosphorus will be absorbed first on the surface of the latter. Only after the sorption capability of iron hydroxide is depleted, will phosphorus bind with calcium.

The quantity of phosphorus bound to iron and aluminum hydroxide and organic matter (NaOH-P fraction), which is far less mobile, comprised a substantial part of the sediment phosphorus ranging from 0.076 (B5) to 2.805  $\text{mg P g}^{-1}$  d.w. (P6) (Fig. 4). The quantity of the NaOH-P fraction rose as the depth the samples were collected from increased and exhibited a link to the aluminum in the sediments ( $r = 0.862$ ,  $N = 12$ ,  $P = 0.01$ ) and the organic matter ( $r = 0.831$ ,  $N = 12$ ,  $P = 0.01$ ), which corresponds to the results of studies by Kentzer (2001).

The practically insoluble fraction of res-P ranged from 0.081 (S0.5) to 1.732  $\text{mg P g}^{-1}$  d.w. (P6). These values were similar to those from other lakes (Kentzer 2001, Kowalczywska-Madura et al. 2005). The ratio of Fe:P was also advantageous for the sediments to bind phosphorus. Marsden (1989) reported that at ratios lower than 3.0, the sediments release phosphorus into the water. In Lake Licheńskie, the mole ratio of Fe:P fluctuated within the range of 2.0 to 20.7. The lowest value (2.0) was noted only at site P6, where the maximum phosphorus content (6.232  $\text{mg P g}^{-1}$  d.w.) also had the highest share of the most readily released fractions ( $\text{NH}_4\text{Cl-P}$  0.074  $\text{mg P g}^{-1}$  d.w. and BD-P 0.293  $\text{mg P g}^{-1}$  d.w.). This was due to the inflow of pollution through the Licheński Canal and its settling in the outlet zone. In the other zones of the lake, the value of the mole ratio of Fe:P was higher than 3.0. This, in combination with the high fraction of res-P in the sediments of the studied lake as well as the low value of the most readily released fractions ( $\text{NH}_4\text{Cl-P}$  and BD-P) indicate that the sediments of Lake Licheńskie effectively store phosphorus compounds.

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## STRESZCZENIE

### CHARAKTERYSTYKA SKŁADU CHEMICZNEGO POWIERZCHNIOWEJ WARSTWY OSADÓW DENNYCH JEZIORA LICHEŃSKIEGO

Celem badań było określenie składu chemicznego powierzchniowej warstwy osadów Jeziora Licheńskiego, ze szczególnym uwzględnieniem komponentów wiążących fosfor w osadach. Osady pobrane z różnych stref jeziora (rys. 1) różniły się między sobą stopniem uwodnienia i miały charakter mineralny

(rys. 2). Składnikiem dominującym ilościowo w osadach wszystkich stanowisk były wapń i węglany (maksymalnie do 39,67% CaO s.m. i do 31,09% CO<sub>2</sub> s.m.; rys. 3), deponowane jako węglan wapnia, na co wskazywała stwierdzona wysoce istotna dodatnia korelacja ( $r = 0,981$ ,  $N = 12$ ,  $P = 0,01$ ) oraz krzemionka (15,5-85% SiO<sub>2</sub> s.m.). Pozostałe składniki z reguły występowały w maksymalnych zawartościach w osadach pobranych z najgłębszego miejsca jeziora z wyjątkiem profilu B. Zawartości materii organicznej były niewielkie (0,83-14,05% s.m.), podobnie jak ilości żelaza i glinu (do 7,15% Fe<sub>2</sub>O<sub>3</sub> s.m. i do 6,43% Al<sub>2</sub>O<sub>3</sub> s.m.). Ilości azotu ogólnego były niskie i sięgały do 1,60% N s.m.

Większość fosforu osadowego była związana we frakcji praktycznie nierozpuszczalnej res-P, średnio (NaOH-P) i trudno (HCl-P) rozpuszczalnej, co pozwala dość trwale blokować fosfor w osadach dennych (rys. 4). Osady Jeziora Licheńskiego pozostają pułapką dla fosforu w warunkach ograniczonego dopływu zanieczyszczeń ze zlewni.