FUNCTION OF LAKE DEPOSITS IN UNDERGROUND WATER EXCHANGE (PERMEABILITY OF BOTTOM SEDIMENTS)

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Introduction

The aim of the research conducted since year 2000 at the experimental chain connected lakes Seven Lakes Stream catchment is to describe relation between lake water and groundwater during an extreme hydrological conditions. Past observations showed great impact of atmospheric water exchange on analyzed relation (Nowicka, Lenartowicz, 2004, Nowicka, 2006). Water balance calculations indicate the drainage of groundwater by lakes in very wet periods. During drought periods the main direction of the exchange turns and lakes supply the aquifer. Course of the process and its size are the results of influence of many factors: hydrological type of lake, location in the catchment, shape of the lake basin and hydrogeological conditions. However, Lee (1977) emphasizes the relation between groundwater and lake mostly depends on features of direct contact zone of groundwater and bottom sediments filling lake basin. Many authors attribute low permeability to lake deposits properties (for example Bartoszewicz et. al., 1998 Dobak, Wyrwicki, 2000). Thickness of those sediments can be significant and in some cases higher than lakes' recent depth. Therefore, in the mathematical hydrodynamic models of water exchange there is a "barrier zone" defined around lakes basin. It simulates the low permeability layer of bottom sediments (Haitjema, 2002). On the other hand seismoacoustic research shows the deposits do not fulfill the lake bowl evenly (Kowalewski, 2006). Thickness and structure of the sediments is different in the lake basin. Zones of groundwater supply can be clearly separated (Harvey et. al., 1997). Often sediment types varying with physical features are classified depending on the chemical composition. Taking into consideration above-mentioned issues question must be asked: to what extend diversity of bottom sediments has influence on deposit infiltration features? The answer for this question provides a basis for precise description of water exchange in lakes. The aim of the following work is the recognition of filtering features of upper layer of different types of the lake sediments.

Investigated lakes

The research was conducted in lakes located on sandur areas in the South Pomeranian Lake District. There were five lakes representing four trophic types selected for the research. (Figure.1).

Three of them, located in post-glacial channel, are harmonic ribbon lakes included in the outflow system of Seven Lakes Stream. The first lake, Ostrowite is situated at the beginning of a cascade structure. This is the alpha-mesotrophic lake with well oxygenated water. Its maximum depth exceeds 43 m. Other two lakes Główka and Płęsno are characterized by a little bit higher water eutrophication. According to Zdanowski and Stawecki

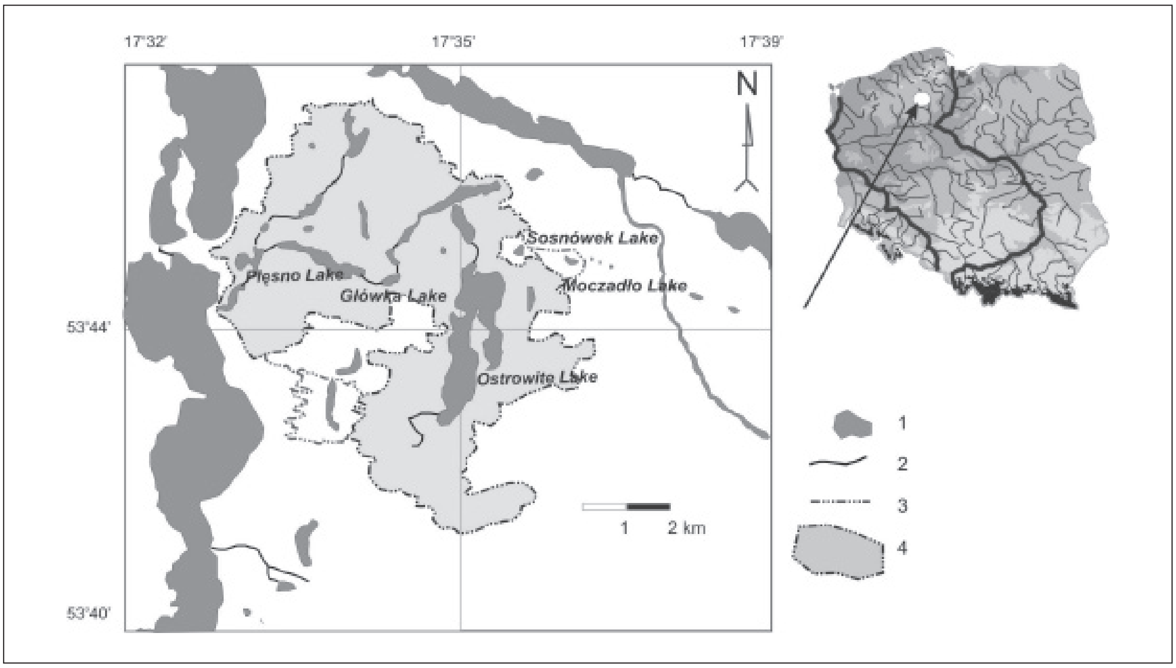

Figure 1. Location of investigated lakes in the South Pomeranian Lake District. 1– lake; 2 – stream; 3 – watershed; 4 – Seven Lakes Stream cachment

(2004) these are meso-eutrophic lakes. The common feature of water bodies is a lack of oxygen at the depth of 5 m (the maximum depth 11 m). It is the result of putrefaction at the lake bottom. In the nearshore zones of the lakes spring zones were located.

Other water bodies are disharmonic landlocked lakes. Theirs depth does not exceed 10 m. Lakes represent different stages of evolution. First of them, dystrophic polihumus lake (Sosnówek) is located in a deep kettle hole. The second one (Moczadło) is situated in a post-glacial hollow. The shoreline is well developed. This is dystrophic oligohumus lake.

Data and method of analysis

Research is based on the following data:

– bottom sediments were analyzed in three different parts of the lake basin (the nearshore zone, on the slope and in the middle – lake depression) to the depth of 16 m;
– only upper layers of lake sediments (maximum thickness 1 m) were analyzed;
– cores were taken by scuba diver with a transparent plexi cylinder containers. It allowed to follow macroscopic changes of the bottom deposits depending on depth;
– the Markowski classification (1980) was used to describe the sediments. It rests on chemical composition of sediments (percent content of organic matter, carbonates and other components);
– for the laboratory analyses cylindrical cores have been divided into 10 cm long sections;
– permeability of lake sediments were described by hydraulic conductivity determined by laboratory tests on samples of intact structure;
– seepage intensity coefficient was measured with variable gradient method, without load.

Because of the specific character of lake deposits hydraulic conductivity was determined in a field laboratory immediately after cores collection. Hydraulic conductivity was measured with the falling head permeametr – Kamieński tube (Turek, 1971). Height of the tube was 40 cm and diameter 6 cm. Examined samples (10 cm long) of intact structure were placed in the tube and flooded with lake water. Hydraulic conductivity were calculated using the formula (Turek, 1971):

$$k = \frac{\Delta l}{\Delta T}\left[-\ln\left(1-\frac{S}{h_0}\right)\right]$$

where:

k – hydraulic conductivity [$cm \cdot s^{-1}$], l – length of seepage pathway, height of the examined sample [cm], S – value of the water level fall in time T [cm], T– time of falling the water level by S value [s], h_0 – height of original pressure [cm].

The sediment cores were taken from 16 locations (63 samples). The nearshore zone was represented by 4 locations (20 samples). In the middle – lake depressions also 4 sampling points were chosen (16 samples). On the slope there was twice as much locations chosen (27 samples were analyzed).

Results

According to Markowski classification (1980) sampled sediments represent 7 different kinds of gyttja falling into 3 types (organic, calcareous and non-calcareous mineral). Simplified chemical composition of sediments taken from 3 morphological zones of lakes of different trophy is shown in Figure 2.

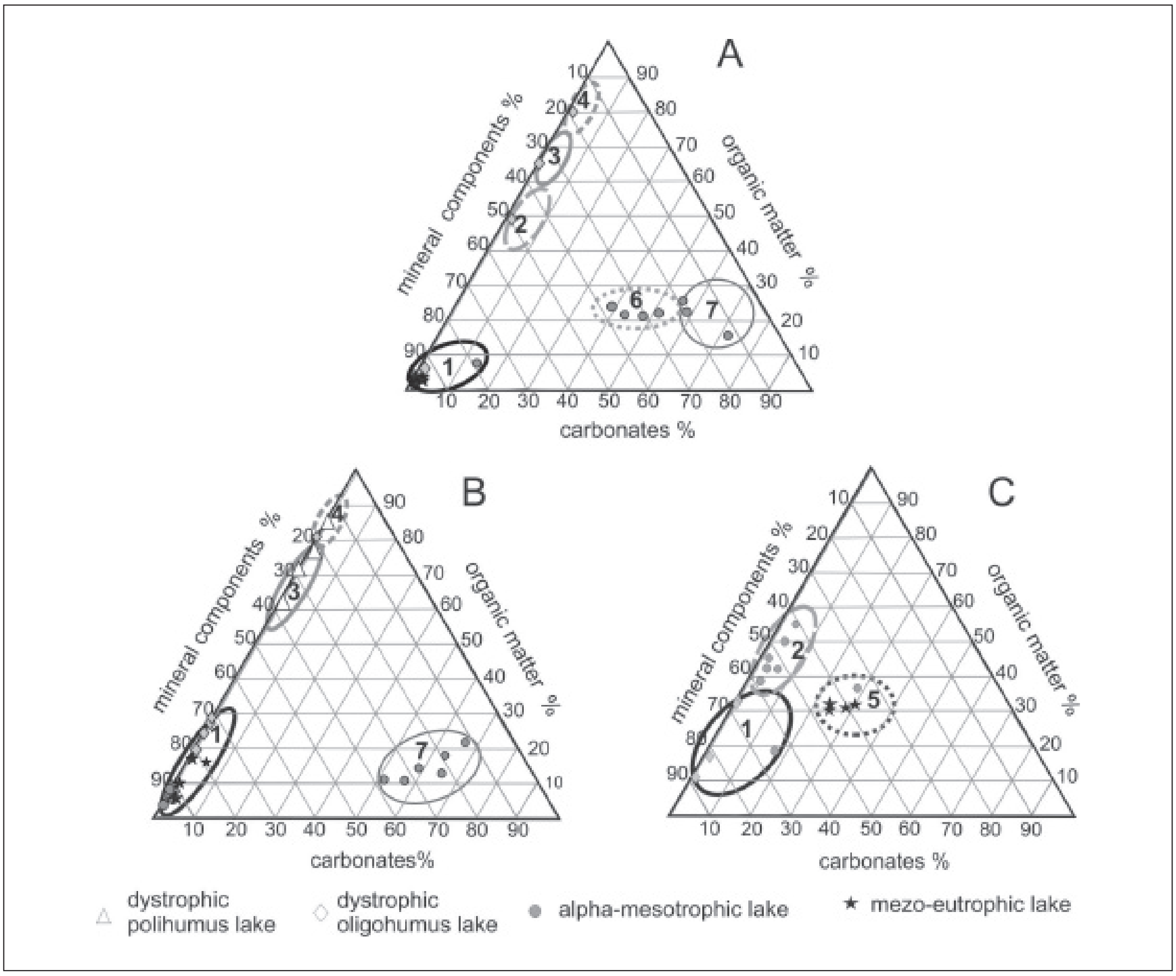

Figure 2. Chemical composition of sediments in researched lakes of different trophy; sample location: A – nearshore zone, B – slope, C – middle – lake depression/ 1. non-calcareous mineral gyttja, 2 – fine detritus gyttja, 3 – coarse detritus gyttja, 4 –algal gyttja, 5- detritus-calcareous gyttja, 6- loamy calcareous gyttja, 7 – calcareous gyttja

Laboratory tests on samples taken from upper layer of sediments showed great variety of hydraulic conductivity (1,4E-07 to 8,7E-05 $m \cdot s^{-1}$). In most cases (49%) value of the parameter varies from 1E-06 to 5E-06 ms^{-1}. According to Pazdro classification (Pazdro, 1971) 36% of samples are taken from semi – permeable aquifers formations. 56% of samples is marked by low permeability and only 8% by medium (Figure 3).

Observed regularities also changes in individual types of sediments. As a rule calcareous gyttja has greater filtering capacity – 61 % of analyzed samples are defined as aquicludes. Only in one case permeability is medium. 71% of organic gyttja samples are marked by low permeability (1E-06 to 5E-06 $m \cdot s^{-1}$). Others are classified as aquicludes. The greatest variety of hydraulic conductivity occurs in non-calcareous mineral gyttja.

In each morphological zone of a lake basins permeability of upper layer of deposits is different. Pelagial sedimentation in the deepest parts of lakes encourages processes of formatting sediments with the greatest filtrating capacity. The arithmetic mean of hydraulic conductivity of samples taken from this part of lake basins is 3,9E-06 $m \cdot s^{-1}$ (standard deviation 1,0E-05 $m \cdot s^{-1}$ and amplitude 4,3E-05 $m \cdot s^{-1}$). Variety of sedimentation processes acting on the slope results in the greatest variability of hydraulic conductivity in this area. The amplitude is 8,7E-05 $m \cdot s^{-1}$ (standard deviation 1,6E-05 $m \cdot s^{-1}$) with the arithmetic mean 5,5E-06 $m \cdot s^{-1}$.

Study documented non-homogeneous insulating features of upper layer of lake deposits. In lake basin appear non-continuous zones of increased filtrating features. The highest hydraulic conductivity (3,0E-06 to 8,8E-05 $m \cdot s^{-1}$) was measured in samples of mineral non-calcareous deposits with minimum admixture of organic matter (Figure 3). Those sediments were taken in the nearshore zone and on the slope in lakes of 3 different trophic types (excluding polihumus dystrophic lake). It seems that such sediments appears increased water exchange zones. On the other hand great variability of hydraulic conductivity in individual cores was found. In successive layers of deposits (10 cm long) hydraulic conductivity can change by order of magnitude. Impermeable interbeds of low thickness can significantly constrain processes of water exchange.

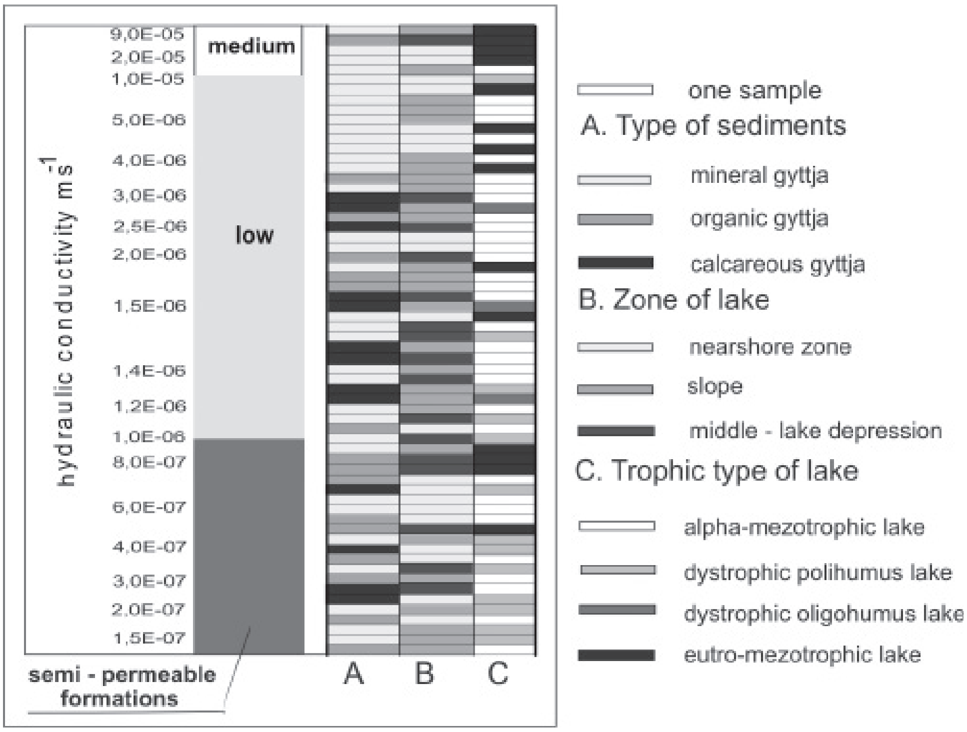

Figure 3. Hydraulic conductivity of samples, depending on: A – type of sediments, B – morphological parts of lake basin, C – trophic type of lake

Conclusion

Results have shown that upper layer of lake sediments is not homogeneous impermeable bed. When “barrier zone” around lakes basin in the mathematical hydrodynamic models of water exchange is defined, we should remember that it is non – continuous and highly variable. On the basis of research samples no regularities referring to variety of infiltration features were found. Hydraulic conductivity varies in broad spectrum regardless of type of sediments and trophic type of lake. This observation applies especially to lake deposits taken from the nearshore zone and on the slope.

References

Bartoszewicz A., Damicz J., Jaromińska M., 1998: *Badania współczynnika filtracji gruntów organicznych*. Mat. II Ogólnopolskiego Sympozjum „Współczesne Problemy Geologii Inżynierskiej w Polsce”, Kiekrz k/Poznania: 117-124.

Dobak P., Wyrwicki R., 2000: *Hydroizolacyjne właściwości kredy jeziornej*. Przegląd Geologiczny, 5: 412-415.

Haitjema H.M., 2002: *Modeling lake-groundwater interactions in GFLOW 2000*, http://www.haitjema.com.

Harvey E.F., Lee D.R., Rudolph D.L., Frape S.K., 1997: *Locating groundwater discharge in large lakes using bottom sediment electrical conductivity mapping*. Water Resources Research, 33(11): 2609-2616.

Kowalewski G., 2006: *Seismoacoustic research of lake Ostrowite*. In: G. Kowalewski, K. Milecka (ed.), *Lakes and mires of Bory Tucholskie National Park*, Charzykowy: 77-86

Lee D.R., 1977: A device for measuring seepage flux in lakes and estuaries. Limnol. Oceanogr., 22(1): 140-147.

Nowicka B., 2006: *Hydrogeology and hydrology of Lake Ostrowite*. In: G. Kowalewski, K. Milecka (ed.), *Lakes and mires of Bory Tucholskie National Park*, Charzykowy: 63-73.

Nowicka B., Lenartowicz M., 2004: *Variability in the process of the lake feeding by the groundwater (case study of small basin in South Pomeranian Lake District)*. F. Maraga and M. Arattano (ed.), *Progress in Surface and Subsurface Water Studies at the Plot and Small Basin Scale*, IHP-VI Technical Documents in Hydrology, 77: 15-20.

Markowski S., 1980: *Struktura i właściwości podtorfowych osadów jeziornych rozprzestrzenionych na Pomorzu Zachodnim jako podstawa ich rozpoznania i klasyfikacji, Kreda jeziorna i gytia*. Mat. konferencyjne, Gorzów Wielkopolski, Zielona Góra: 44-56.

Pazdro Z., 1977: *Hydrogeologia ogólna*. Wydawnictwa Geologiczne, Warszawa: pp 322.

Turek S., 1971, *Poradnik hydrogeologa*, Wydawnictwa Geologiczne, Warszawa: 145-151.

Zdanowski B., Stawecki K., 2004: *Zagrożenia antropogeniczne jezior*. In: B. Zdanowski, A. Hutorowic, W. Białokoz (ed.), *Ekosystemy wodne Parku Narodowego „Bory Tucholskie”*, Wyd. IRS, Olsztyn: 59 -72.