ПРИРОДООБУСТРОЙСТВО И ВОДОХОЗЯЙСТВЕННОЕ СТРОИТЕЛЬСТВО

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WATER BALANCE OF LAKE ŁEBSKO

Chlost Izabela
Department of Hydrology, University of Gdańsk, Poland, izachlost@op.pl

The article contains a brief characteristic of fluctuations in water level in Lake Łebsko in conjunction with the results of calculations of the water balance for 2003-2007. Among the balance elements, special attention was paid to the participation of the inflow of sea water in the water circulation in the lake.

Introduction

Water exchange in lakes and fluctuations in their levels are the result of a dynamic water balance (Bajkiewicz-Grabowska 2002). In the case of Lake Łebsko, these processes are influenced by its location in the coastal zone of the Southern Baltic Sea (Fig. 1). The lake gathers water naturally from its catchment and the water forced from the surrounding polders. Incidentally, the lake is a recipient of marine waters. This is possible thanks to the mouth section of the Łeba connecting the lake to the sea.

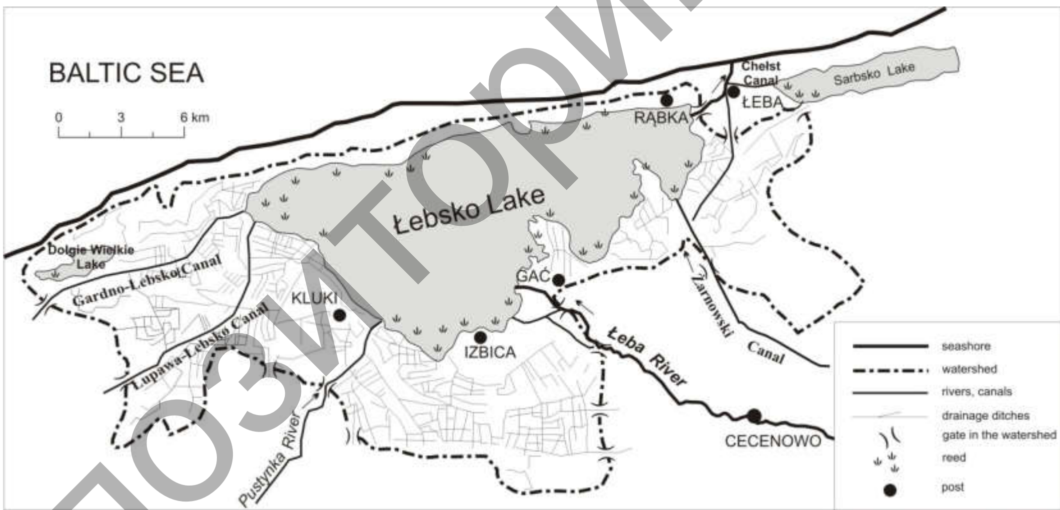

Fig. 1 *-Hydrographic outline of the Lake Łebsko immediate basin*

This link determines a close hydraulic connection of both water bodies. The volume of the terrestrial runoff and the volume of the inflow of marine water depends on the current sea level. Often, due to changing hydrometeorological conditions, there is a rapid increase in the sea level, which means that the outflow from the lake is blocked. Such a phenomenon of may even diverted drop and the evoke the inflow of marine water from into the lake. This causes certain repercussions in Lake Łebsko, both quantitative and qualitative.

The aim of the study was to determine the correlation between potamic, atmospheric and marine inflow and the seasonal fluctuations in water level in Lake Łebsko. Moreover, it aimed at recognising the size of various forms of water supply, with particular reference to the participation of the inflow of marine water in the lake water circulation.

Materials and methods

The study was based on observations of water levels recorded at the gauging station in Izbica. Annual average and extreme states were analysed for the years 1965-2007, while daily states for 1992-2007. Water balance of the lake was calculated for the years 2003-2007. Water inflow from the Łeba basin was based on the daily flow of the Łeba at the gauging station in Cecenowo, monthly values of the Pustynka (Cieśliński 2008), as well as daily values of the water inflow from the seven currently active polders located in the immediate catchment of the lake. To determine the components of the vertical exchange of water balance and anemometric data necessary for their calculation, the data from the gauging stations in Łeba and Gacie were used. To determine the size of the daily evaporation from the surface of the water the Penman formula used, and to determine the sublimation during periods of ice cover of the lake – the Ostromęcki formula (Kossowska-Cezak, Bajkiewicz-Grabowska 2009). The inflow of the marine water into the lake was estimated for the periods when the water level of the Baltic Sea in the port of Łeba was higher than the level of the lake in Izbica. These periods were determined by comparing the states of the two bodies of water after bringing data to a common gauge zero. This method was successfully used before by other hydrologists (Mikulski 1970, Mikulski et al. 1969, Balicki 1977). To calculate the volume of the marine water inflow, the bathygraphic curve of the lake was used, assuming that intrusions inhibit the outflow from the lake and increase the resources in the lake basin. The volume of marine water inflows was received by subtracting the inflow from it the inflow from the river basin and immediate catchment To simplify calculations it was assumed that the surface of the lake does not change in spite of fluctuations in water levels (Weber 1973).

Due to the difficulty in determining the underground inflow and outflow, it was assumed that these components are in balance and thus were omitted. The outflow from the lake was calculated from the balance equation.

General characteristics of the water levels in the lake

Fluctuations in the water level in Lake Łebsko show high volatility and irregularity. The average water level in Lake Łebsko in the years 1965-2007 was 508 cm; in the years under detailed examination, i.e. 1992-2007, the level was higher by 3 cm. In the latter period, the highest water level frequency ranged from 500 to 509 cm, while the specific states were as follows: low states zone (458-491 cm) – 15.6%, middle states zone (492-523 cm) – 62.8%, and high states zone (524-588 cm) – 2.6%.

The hydrological regime of Lake Łebsko is complex. The annual course of the water level fluctuations shows two maxima. The first one, well pronounced, is recorded in the winter half-year, in February (Fig. 2), when the lake is a recipient of very intense inflow from its catchment basin. At the same time water levels in the lake are shaped by storms resulting from the low-pressure systems moving over the Baltic Sea.

The second, much smaller maximum is recorded in the summer months, mostly in July or September. This maximum is, in turn, determined by increased precipitation. A well pronounced minimum is recorded in May and coincides with the seasonal decrease in the level of the Baltic Sea, the end of the inflow of snowmelt waters to the basin and relatively limited atmospheric supply.

High water level in the lake is usually recorded in the winter half-year. However, there are years in which higher states are recorded in the summer half-year (31.2% of cases). As a rule, this has to do with the long-term ice phenomena of the cold period, the consequence of which is limited supply of potamic and atmospheric water. Ice cover on the lake is observed every year. It appears the earliest in mid-November, and disappears the latest around 10 April. It is frequently broken by ice-free periods. The phenomenon of lowering the level of the lake water as a result of compact and long-term ice cover was recorded, for instance, in 1996, the year in which the absolute minimum for the years 1992 to 2007 (461 cm) was recorded, and the ice persisted over 120 days (Chlost, Cieśliński 2005). Such a situation repeated in 2003 (74 days of ice phenomena) and 2006 (85 days of ice phenomena). In the other years (2001 and 2004), high water levels in summer need to be associated with the then increase in the Baltic Sea water level, which resulted in the increased frequency of marine water intrusions into the lake.

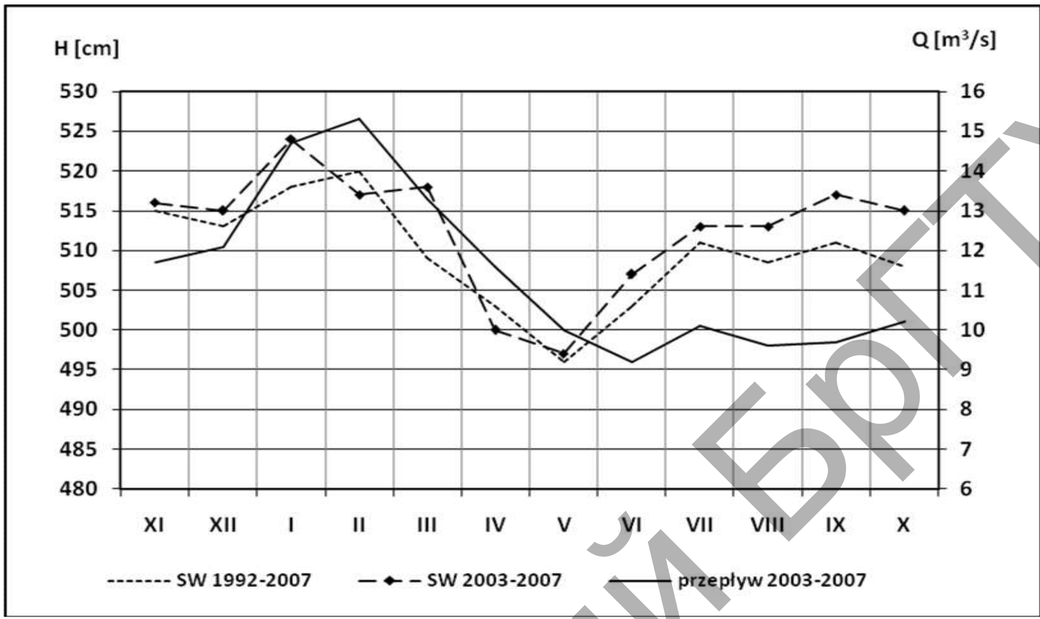

***Fig. 2** – Course of average monthly water levels in Lake Łebsko in 1992-2007 and in the balance period of 2003-2007 as well as the average monthly flow of the Łeba in Cecenowo*

Annual range of the water level fluctuations often exceeds 1 m (Chlost, Cieśliński 2005), which is characteristic of coastal lakes (Choiński 1985). The absolute range value for the investigated lake in 1965-2007 was 130 cm. At that time, the limit value of 1 m was reached or exceeded in 7% of cases.

Water balance

Evaluation and quantitative assessment of the amount of water taking part in circulation in the basin of Lake Łebsko was undertaken by earlier studies of several authors, incl. Mikulski (1970), Majewski (1972), Weber (1973) and others. The results for 2003-2007 are illustrated in Figure 3.

The lake balance sheet is dominated by the supply of inland waters, which represent almost 65% of the total inflow (Fig. 3). Of this volume, up to 360 million m3 (81.1%) is supplied by the Łeba, and less than 70 million m 3 (15.6%) by the Pustynka. The polder system provides only 3.3% of the total volume of the inland waters. In the subsequent years potamic supply and the inflow from the pumping stations was 387-498 million m3.

For calculating the balance it is essential to estimate the inflow of marine waters into the lake. The results of calculations indicate that such intrusions make up ⅓ (almost 228 million m3) of the total supply. Saline water intrusions are possible as a result of the water level in the lake, which is slightly above the sea level. The specialist literature mentions diverge values of the level ranges, from 30 (Jańczak 1997) to 8.6 cm (Szopowski 1958). In the period covered by the balance this difference was 7 cm on average and was calculated on the basis of the average level of Lake Łebsko at the gauging station in Izbica and mean sea level in Łeba, taking into account the difference of the gauging zero which is 1 cm. The share of marine waters in the horizontal exchange was calculated taking into account changes in the level of the lake caused by inflow from the catchment. The calculations included the deduction of the volume of the river inflow from the water layer formed by periodically prevailing water level in the sea over the state of the lake (Mikulski 1970, Weber 1973). This eliminated intrusion days, when the sea level exceeded the level of water in the lakes by 1-2 cm, and occasionally approx. 3 cm.

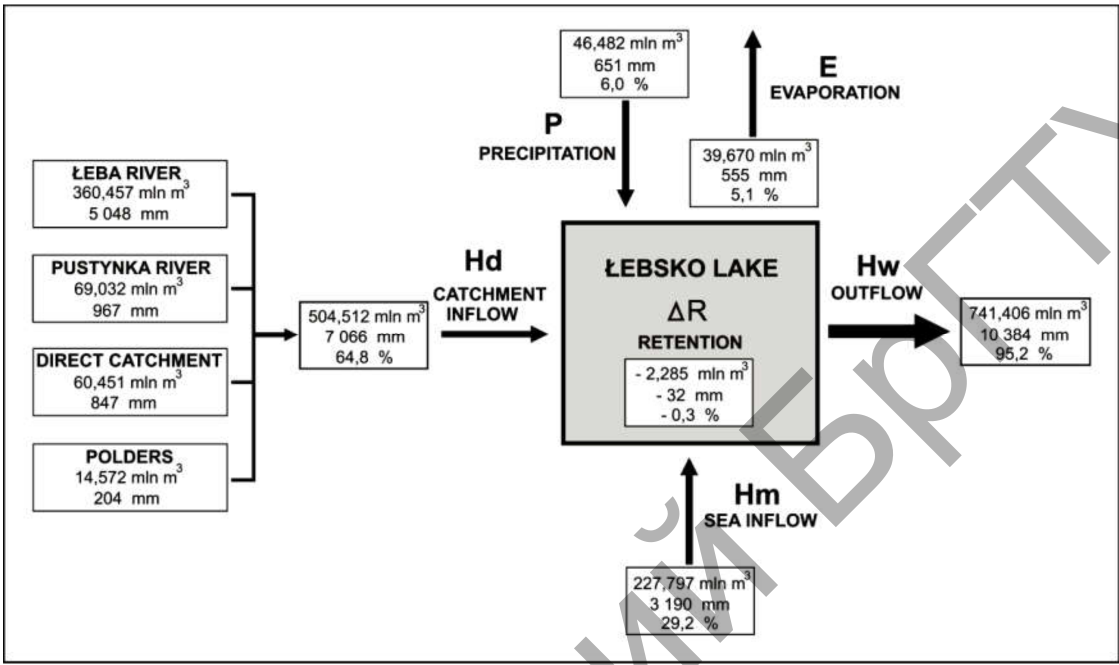

***Fig. 3** – Average water balance of Lake Łebsko: 2003-2007*

The months with the highest chance for an intrusion were June (14%) and December (11.1%), while the lowest number of marine intrusions was recorded in April (2.7%) and February (3.8%) (Fig. 4). It follows that the inflows occur most often in the spring months in which the water level of both water bodies is very low with the difference between them small and the limited supply from the basin (June, May). Intrusions occur least frequent during the snowmelt outflow (April) and large inflow from the mainland (February).

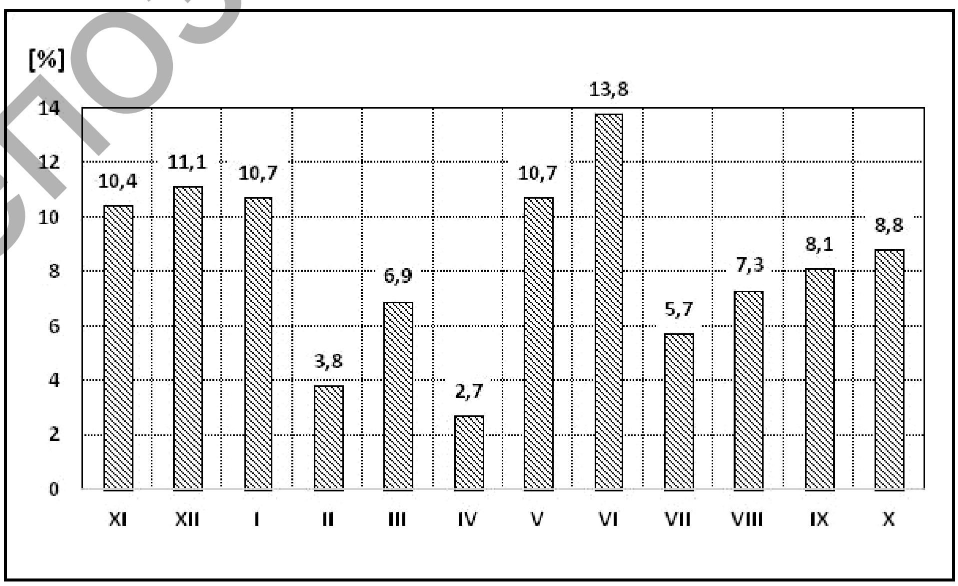

***Fig. 4** – Proportion of days with the marine water inflow into Lake Łebsko: 2003-2007*

Given the volume of water supplied, both in the case of water inflowing from the land and from the sea, the largest recorded was in the winter half-year. Maximum supply from the basin was in January and February (together over 20%), while from the sea side, these values were dominant in December and January (nearly 30%).

The volume of the outflow from the lake to the sea was more than 95% of the outgoing side of the balance sheet. In the annual balance the largest outflow was recorded in the winter months, from December to April (with a maximum in January), as well as in October. They were also months of high-volume inflow from the catchment basin and atmospheric supply. The size of the outflow in a simple way also determined the value of the lake retention. It was responsible for the change in the lake capacity in the balance period (Bajkiewicz-Grabowska 2002). In 2003-2007 the lake retention volume took a negative sign in the winter half-year, and positive in the summer. This shows that during the first half of the hydrological year, especially in February-April, the water resources of the lake were gradually reduced, despite the increased supply, as referred above. This was reflected in the low water levels in the lake recorded from the beginning of May (Fig. 2). The retention level was regulated by the fluctuations of the main drainage base.

Vertical components of the water balance for Lake Łebsko were of secondary importance. The atmospheric phase of the water exchange was dominated by evaporation. The average annual evaporation from the surface of the water was 56.2 million m3, which with regard to the surface unit of the lake was 787.4 mm (Chlost 2009). In the subsequent balance years the size of evaporation varied and ranged from 723 mm in 2004 to 918 mm in 2007. Only in 2004 the recorded sum of evaporation was lower than rainfall. The difference between evaporation and precipitation was significant, and in 2005 amounted to almost 290 mm.

In 2003-2007 average precipitation on the surface of the lake was 631.6 mm, which represented 6.5% of the total inflow and gave a little more than 45 million m3 of water volume. Basically, in the autumn and winter months, mainly from October to February, the vertical exchange was dominated by precipitation. From early spring, though, the share of evaporation was gradually increasing, which only occasionally was compensated by relatively high summer precipitation. This was reflected in a slight (only 23 mm) predominance of rainfall in the winter half-year and large (179 mm) dominance of evaporation in the warm season.

Water exchange

The water exchange rate of a lake is shown by the ratio of the volume of the outflow water from the lake to its capacity. In the case of Łebsko the amount of water involved in the exchange is determined by its location in the basin of the Łeba and in the vicinity of the Baltic Sea. Being in the hydraulic connection with the sea, the lake has much more favourable conditions for a full and rapid exchange of water than inland lakes. The water exchange rate for Lake Łebsko, calculated by Mikulski (1970), is 4.4. The data of the balance elements for 2003-2007 allowed calculating that this ratio at 5.5, and in individual years from 4.1 in 2006 to 6.7 in 2007. Such an indicator is typical for hydrologically active water bodies (Pasławski 1975).

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ПОЛОЖЕНИЕ ОЗЁР НА РАЗНЫХ УРОВНЯХ ТЕРРИТОРИАЛЬНОЙ ГИДРОГРАФИЧЕСКОЙ СИСТЕМЫ КАК ФАКТОР, ФОРМИРУЮЩИЙ ЭЛЕКТРОЛИТИЧЕСКУЮ ПРОВОДИМОСТЬ ВОДЫ

Камиль Новиньски
Кафедра Лимнологии, Гданьский Университет, Гданьск, Польша,
geokamil@univ.gda.pl

The article describes influence of lake's location in the spatial hydrographic system on water conductivity of lakes. Water properties are dependant on water supply structure which is determined by location within the spatial hydrographic systems. Lake location in the system determines proportions between the surface and underground water supply and capacity of reservoirs to increase the outflow.

Введение

Условия водообмена и структура питания озёр поставлены в зависимость от их размещения в пределах территориальных гидрографических систем [Дрваль 1982, 1985] и линейных речно-озёрных систем [Байкевич-Грабовска 2002]. Помещение озера в системе решает вопрос о пропорциях между поверхностным и подземным питанием и о способности бассейнов к увеличиванию отлива. Структура питания отвечает за изменения свойств воды в озёрах. Вода, расположенная в поверхностной фазе вращения, относится к разным этапам циркуляции: от осадков до питания из подземных слоёв. Концентрация заключённых в ней минеральных веществ зависит