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Characteristics of water level fluctuations in Polish lakes – a review of the literature[1]

Charakterystyka wahań poziomu wody w jeziorach polskich – przegląd piśmiennictwa

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Abstract
Water level fluctuations (WLF) in lakes are a natural feature that can be modified by human activities. The article presents a review of literature on the water level fluctuation in Polish lakes, their amplitude, periodicity and trends. WLF controlled by natural conditions and also those induced by human activity were considered. Although anthropogenic water level fluctuations in most Polish lakes seem to fall within the range of natural fluctuations, in some cases economic activities (e.g. the use of lakes for energy generation purposes) can lead to strong disturbances of the hydrological regime, causing an ecological instability that makes it impossible to maintain/achieve good ecological status. This, in turn, makes it necessary to define good ecological potential, being an environmental objective for such water bodies, which is less rigorous compared with good ecological status. The article indicates the need to expand the methods for the assessment of lakes in the country with new biological indicators to assess, in accordance with the Water Framework Directive requirements, the impact of hydrological alterations on biota.

Streszczenie
Wahania poziomu wody w jeziorach są ich naturalną cechą, która może być modyfikowana działalnością człowieka. W artykule przedstawiono przegląd piśmiennictwa na temat amplitudy wahań poziomu wody w jeziorach polskich, cykliczności ich fluktuacji i tendencji zmian oraz naturalnych i antropogenicznych czynników warunkujących te wahania. Jakkolwiek wywołane antropogenicznie wahania poziomu wody w większości jezior polskich wydają się mieścić w zakresie wahań naturalnych, to w niektórych przypadkach działalność gospodarcza (np. wykorzystanie jezior na cele energetyczne) może prowadzić do silnych zaburzeń reżimu hydrologicznego, powodujących destabilizację ekologiczną zbiornika eliminującą możliwość utrzymania/osiągnięcia dobrego stanu ekologicznego. To z kolei pociąga za sobą konieczność sprecyzowania dobrego potencjału ekologicznego, jako celu środowiskowego dla takich części wód, mniej rygorystycznego w porównaniu do dobrego stanu ekologicznego. W artykule wskazano potrzebę poszerzenia sposobu oceny jezior w kraju o nowe biologiczne wskaźniki oceniające, zgodnie z wymaganiami Ramowej Dyrektywy Wodnej, wpływ przekształceń hydrologicznych na zespoły organizmów.

1. INTRODUCTION

Water level fluctuations (WLF) in lakes depend on many natural factors, such as the intensity of surface and underground recharge, evaporation from the free water surface, plant transpiration, river flow and precipitation, with the strength of their impact varying in time and space. Moreover, the natural rhythm of the recharge of the lake bowl with water is increasingly often modified, e.g. by damming up or lowering the water level. Water abstraction or discharges of wastewater or cooling water can also affect the water levels in lakes [Pasławski 1988, Dąbrowski 2001, Górniak 2001, White et al. 2008]. In consequence, the conditions of nutrient supply from the catchment can also be modified, e.g. the surface runoff can intensify. This is an important problem since with rising or falling water levels in lakes aquatic habitats emerge or decay; moreover, the physical features of water and its chemical features can change, affecting the intensity of the eutrophication process.

The exploration of the scale of the water level fluctuation phenomenon in lakes is related to the implementation of the assumptions of Directive 2000/60/EC, called the Water Fremework Directive (WFD) [EU 2000] and the need to meet, at the same time, the requirement for mitigating the impacts of floods and droughts (involving a small retention programme) and the environmental objective (the achievement of good status of waters by 2015). Changes in the hydrological regime of a lake are an element of an assessment of hydromorphological alterations, which is part of an assessment of the ecological status of lakes in accordance with WFD, as well as one of the grounds for designating heavily modified water bodies, pursuant to the same Directive.

Since 1995, the Regional Boards of Land Amelioration and Water Facilities have implemented a small retention programme. The purpose of this programme is to enhance the available resources of surface waters and groundwater that are of importance for agriculture, forestry and nature protection. One of the forms of the implementation of this programme is the damming up of small lakes and the capacity to regulate their outflow. These measures can cause significant changes in the type and range of the littoral

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zones of lakes, enhancing or reducing its biodiversity and affecting the catchment–lake interactions.

In Polish lakes, there are both natural and anthropogenic water level fluctuations that impact the ecosystems of these reservoirs. However, to date their ecological effects have been poorly explored in the domestic literature.

The aim of this paper is to make a review of data on the spatial range and scale of annual and long-term vertical water level fluctuations in Polish lakes. It will constitute the starting point for the exploration of the impact of natural and anthropogenic water level changes on the biota and for development of specific criteria for ecological potential assessment. At a later date in the future, this work can also provide the theoretical foundations that will make it possible to take planned and purposeful measures addressing lake ecosystems to mitigate the adverse impacts of their excessive eutrophication, particularly the blooms of blue-green and other algae.

2. NATURAL FACTORS DETERMINING WATER LEVEL FLUCTUATIONS IN LAKES

Natural water level fluctuations in a lake are some of the characteristics that reflect the regime of the lake. In terms of the causes of fluctuations, they can be divided into those related to a change in the quantity of water in the reservoir bowl and those that do not change the volume of a lake [Choiński 2000].

The former ensue from the climate conditions that affect the loss and supply sides of the water balance. In turn, the latter results from changes caused by short-lasting movements within a reservoir, such as undulation, currents and seiche waves [Mikulski 1963, Choiński 2000].

Water balance of a lake should be considered when analyzing water level fluctuations. It is influenced by both the meteorological factors (temperature, quantity and distribution of precipitation, wind speed) and physiogeographical variables (afforestation, river network density, soil permeability, the shape of a catchment). Mikulski [1970] proposed a balance equation, covering both the vertical water exchange (between the lake and the atmosphere) and the horizontal one (between the catchment and the lake). In such a case, the balance equation takes the form:

$$\Delta R_j = (P_j - E_j) + (H_d - H_w)$$

where:

ΔR_j – the difference in the retention at the beginning and the end of the balance period; it means a change in the water level in the lake,

P_j – the precipitation on the lake surface,

E_j – the evaporation from the lake surface,

H_d – the inflow to the lake (surface and underground),

H_w – the outflow from the lake (surface and underground).

The water balance of a lake can also be affected by animals, e.g. beavers (*Castor fiber*). When adapting the natural environment to their needs by building dams on watercourses, these animals cause a rise of the water level in reservoirs, as well as flooding and inundation of the areas adjacent to the watercourses [Rurek 2008].

Many authors point out that natural fluctuations in lakes are also affected by the geophysical conditions and solar activity [Andreeva 1973, Bendefy 1973, Michalczyk and Turczyński 2001].

Apart from the amplitude of the water level fluctuations related to the recharge of the lake, it is necessary to consider factors that do not affect the lake volume, but cause temporary fluctuations in a part of the reservoir:

1) The undulation phenomenon that is caused by the strength of the wind; thus, it is a phenomenon forced on the lake surface water. The maximum wave size can vary. The spatial distribution of the wave is an effect of both the impact of the wind on a given area of the lake and the effective lake length. The water level rise is the greater, the faster the wind speed and the greater the effective length of the reservoir are, but the lesser its depth is [Choiński 2000]. The undulation in Polish lakes emerges only under the impact of wind speeds of at least 1–2 m/s. The maximum observed wave height reaches 1 m [Mikulski 1963].
2) Seiche waves, i.e. free standing waves arising in lakes as a result of a difference between the pressures at the ends of a reservoir. To a large extent, the scale of this phenomenon depends on the size of a reservoir. The fluctuation period of seiche waves varies between several and several dozen minutes and their size between several and several dozen centimetres [Choiński 2007].

3. ANTHROPOGENIC FACTORS INFLUENCING WATER LEVEL FLUCTUATIONS IN LAKES

The deforestation of a catchment significantly affects the water circulation in it and determines water level fluctuations in lakes, changing the elements of the water balance in the catchment [Ciepielowski 1999].

Farming exerts a direct impact on the quantity of water resources in a catchment through water consumption. In turn, its indirect impact consists of changes in the conditions of seepage, surface flow and retention capacity of soils [Ciepielowski 1999].

Urban building prevents the infiltration of rainwater and meltwater. It diminishes the natural retention in the catchment and speeds up the surface flow rate (the flow occurs immediately after a precipitation event) [Bednarczyk et al. 2006].

A strong expansion of a rainwater collection system can cause a decrease/increase in the catchment area of a given lake. This happens when rainwater is transferred through a collection system from the catchment of one reservoir to another catchment and, thus, reduces/enlarges the supply source [Jeznach 1999].

The energy generation by hydropower plants has a substantial effect on the water regime in the rivers and lakes that they utilise. Heated water discharges from power plants affect the water balance of lakes since they enhance the evaporation from the reservoir [Sziwa et al. 2003]. When pumped-storage power plants pump out water from their lower reservoir (the lower reservoirs are often lakes of natural origin) to the upper reservoir (most often artificial reservoirs), they generate very large water level fluctuation, greatly exceeding their natural fluctuations [Lech 2006]. The construction of such power plants also causes changes in the microclimate [Szramka and Różycki 1999].

Lake retention mainly consists of the damming up of natural reservoirs by means of hydro-engineering structures. The level of such damming up should be determined on a case-by-case basis for each water area in order to avoid its adverse impact on the surroundings. Lake water levels should be controlled within a natural fluctuation interval [Bielakowska, no date].

4. WATER LEVEL FLUCTUATIONS IN POLISH LAKES: A REVIEW OF THE LITERATURE

Right from their inception, lakes continuously evolve. Their evolution leads, as a rule, to their overgrowing and then their decline.

Water level fluctuations are one of the major factors that determine the shape and character of a reservoir [Marks 1992].

The issues of water level fluctuations in Polish lakes in contemporary times are not very often considered in the literature. This is mainly due to: scarce source materials and a small number of lakes examined (it was only after 1970 that the number of lakes surveyed for this purpose grew). Historic data often have gaps in measurements [Borowiak 2000]. The main issues considered by hydrologists include the amplitude, cyclicality and trends of fluctuations.

4.1. The water level fluctuation amplitude in Polish lakes

Analysing the character of water table fluctuations, Choiński [2007] distinguished the following five lake types:

- **Type A** (coastal lakes) – characterised by fluctuation amplitudes exceeding 100 cm. These lakes may not demonstrate a dependence between water level fluctuations and water levels in rivers feeding into them. The maximum and minimum water levels may occur in different periods.
- **Type B** (flow-through lakes) – a characteristic feature of these lakes is a fluctuation amplitude that most often does not exceed 50 cm. The behaviour of the water level in a lake is strictly related to the water level in the river that feeds into the lake. The extreme water levels mainly depend on the recharge by rainfalls and snowfalls.
- **Type C** (lakes with an outflow) – the fluctuations in these reservoirs fall within an interval of 50–100 cm. The fluctuations mainly depend on the recharge by groundwater and they are mitigated by the outflow of a watercourse from the water area.
- **Type D** (lakes without an outflow) – the behaviour of fluctuations is similar to that in lakes with an outflow. However, in this case there is no mitigating impact of the outflow. To a large extent, the variability rhythm in these reservoirs is related to the groundwater table fluctuations.
- **Type E** (mountain lakes) – the water table fluctuations in these lakes often exceed 100 cm. This is caused by their specific recharge. The differentiation of fluctuation amplitudes in mountain lakes mainly depends on the size of the topographic catchment. The minimum water levels are recorded at the moment that the lake is covered with ice, whereas the maximum water levels occur during the spring thaw.

Mikulski [1963] holds that the long-term water table fluctuations in Polish lakes without human interference fall within an interval of 30–50 cm. It is only coastal lakes subjected to sea water inflows that reach fluctuations of the order of 1 m. The annual fluctuation cycle is characterised by high regularity. The maximum levels occur right after the ice cover vanishes (approximately in April), whereas the minimum levels come in the autumn (October-November).

According to Jańczak [1996–1999], the fluctuation amplitudes in most lakes in the Polish territory in 1955–1995 fell within an interval of 20–40 cm. Fluctuations exceeding 0.5 m occurred sporadically. Fluctuations exceeding 1 m occurred in single lakes, resulting primarily from human interference and extreme hydrological events. There was also a large group of lakes where the fluctuation amplitudes were not greater than 20 cm. The author holds that the mean annual water levels depend on the climate conditions, whereas the fluctuation amplitude mainly ensues from the conditions of water circulation in the lake catchment.

Analysing the measurement series carried out in 1961–1995 in 48 Polish Lowland lakes, Borowiak [2000] found that the maximum fluctuation amplitude occurred in coastal lakes and those closing large basins. Among the lakes surveyed, the largest fluctuation amplitudes were found in Lakes Bachotek and Gopło (110 cm each) and in Lake Rajgrodzkie (106 cm). Coastal lakes were characterised by fluctuations of the order of 90–100 cm. The smallest fluctuations occurred in lakes situated in the watershed zones: Lake Jesień (18 cm), Lake Betyń (23 cm) and Great Lake Dąbrowa (27 cm). As a result of specific local conditions (e.g. the geological structure), some disturbances can emerge, such as those in the case of Great Lake Bobięcińskie (46 cm) and Lake Hańcza (59 cm). In the period analysed, lakes demonstrated a positive trend in the position of the mean water table level. The reasons for the emerging inversions relative to the general trend should be sought in anthropogenic activities.

When calculating the elements of the water balance for Lake Sławskie, Rösler [2000] found that the water level difference for the period 1980–1990 was 25 cm. Thus, the average retention loss was represented by a layer of 25 mm per year. However, the retention in the whole balance period was different in the individual years, varying from +120 mm (1987) to – 300 mm (1982).

On the basis of 10-year observation series carried out by the Institute of Meteorology and Water Management in Charzykowy in 1991–2001, Nowicka [2003] found that the water level amplitude in Lake Charzykowskie in that period was 96 cm and that the lake was characterised by two periods of high water levels: March–April and July–November.

The characteristics of water level fluctuations in Lake Łebsko were presented by Chlost and Cieśliński [2005]. Data came from the period 1992–2003. Throughout the research period, the monthly fluctuation amplitude was 73 cm. In turn, the annual fluctuation amplitude varied from 32 cm in 1994 to 55 cm in 1996. The water regime in Lake Łebsko is determined, on the one hand, by tributaries feeding into the lake and, on the other, by the hydrodynamic conditions related to the Baltic Sea. Still, the impact of the sea is more conspicuous, resulting in the dynamic behaviour of water table level fluctuations. A strong dependence between the water levels in the lake and the sea can also be seen.

The water level fluctuations in Lakes Kłeckie and Gorzuchowskie (the Gniezno Lake District) in the hydrological years 1999/2000–2004/2005 were surveyed by Kanclerz et al. [2007]. The variability of water levels in these natural reservoirs demonstrated cyclical seasonality determined by the weather conditions. The maximum water levels followed the spring thaw, whereas the minimum ones occurred in October. The fluctuation amplitudes in the survey period varied between 32 and 105 cm.

In 1991–2010, Michalczyk et al. [2011] surveyed the water level fluctuations in 38 lakes in the Łęczna-Włodawa Lake District. These lakes showed differentiated dynamics. The water regime and balance of the lakes were determined by the land amelioration activities carried out in the 20th and 21st centuries and the coal mining in this area. Low water levels were observed in 1994–1996 and 2003–2005, whereas high levels were recorded in 2002 and 2010. The fluctuation amplitudes in lakes with natural hydrological conditions varied from 43 to 110 cm.

The Great Masurian Lakes (GMLs) are a system of navigable lakes. The water management in these reservoirs makes it necessary to maintain the water table levels at 115.55–116.00 m a.s.l. (with a 45 cm fluctuation). The water levels are regulated with sluices and weirs [Regional Water Management Authority in Warsaw 2012]. The lake levels in the period from 1846 to 2000 were characterised by a distinct falling trend; still, such behaviour of the fluctuations was mainly determined by water management and only to a slight extent by natural processes [Dąbrowski 2001].

The impact of damming up weirs on the water levels in four lakes (Bachotek, Ciche, Strażym and Zbiczno), situated on the Skarlanka River, was documented by Skowron [2002]. In these lakes, the water levels were raised by damming up on average by 0.5 m. The greatest damming-up effect was observed in Lake Bachotek. The stability of water levels in this reservoir in the interval between 238 and 302 cm caused the annual fluctuation amplitude to fall from 105 to 35 cm.

The water level observations in Lake Łękuk (within the Borecka Forest in North-eastern Poland) have been carried from October 2003 (the hydrological year 2003/2004). Since beavers settled down there, the water levels in this reservoir have not depended on the weather conditions, i.e. precipitation (Fig. 1). The structures built there by animals in tributaries and outlets affected the water balance of this lake, changing the retention capacity of the water area. The greatest fluctuation amplitude occurred in the hydrological year 2004/2005, amounting to 63 cm, whereas the lowest one was found in 2007/2008, amounting to 17 cm. The mean annual fluctuation for the period analysed (the hydrological years 2003/2004–2010/2011) was 32 cm [Prządka, unpublished materials, provided with the consent of the Chief Inspectorate for Environmental Protection].

The authors of a separate group of studies have attempted to relate the catchment physiography to the variability of water levels. The impact of the catchment area on water levels was already pointed out by Skibniewski [1954], Pietkiewicz [1958] and Mikulski [1963]. But it was only Pasławski [1975] who assessing the water fluctuation amplitudes in lakes by indirect methods derived a formula showing the dependence between the ratio of the total lake catchment area to the lake area and the mean annual water level amplitude. This formula has the form of a power function:

$$\Delta h = 10{,}148\left(\frac{CA}{LA}\right)^{0{,}434}$$

where:
Δh – the annual lake water level amplitude,
CA – the catchment area,
LA – the lake area.

The determination of this dependence made it possible to create a hydrographic and morphological typology of Wielkopolska lakes.

Just as Pasławski [1975] earlier, Jańczak [1991] derived a linear dependence for Wielkopolska lakes between the catchment area proper and the mean annual water level amplitude:

$$\Delta h = 0{,}0655\left(\frac{CA}{LA}\right) + 44{,}485$$

Bajkiewicz-Grabowska [2005] also found dependence between the catchment area and the annual fluctuation amplitude in a lake, which she described by means of the following linear function:

$$\Delta h = 0{,}221\left(\frac{CA}{LA}\right) + 38{,}969$$

Choiński [1985] holds a different opinion regarding the importance of the catchment and lake area for the water table fluctuation levels. The author believes that there is no relationship between the catchment area and the lake area. Therefore, the absence of a relationship between these parameters indicates that the local conditions of a given area affect the water table amplitude.

Hydro-power plants exert the greatest anthropogenic impact on daily water level fluctuations in lakes. The Żarnowiec Hydro-power Plant is the best example of this in Poland. It is situated on Lake Żarnowieckie in the village of Czymanowo. The whole power plant system consists of two reservoirs: the upper and lower ones, and water supply pipelines. The upper reservoir is an artificial one, while the lower reservoir is a ribbon lake. The water table level in Lake Żarnowieckie changes in accordance with the operational rhythm of the power plant. The daily fluctuations in this reservoir that are caused by the operation of the power plant amount to about 1 m [Lech 2006].

Sziwa et al. [2003] examined the impact of integrating the Konin ribbon lakes into the cooling system of the Pątnów and Konin power plants on water level fluctuations and their balance. The water levels in the lakes are artificially regulated. The minimum water level was reduced by 30 cm. The other characteristic water levels did not change. The maximum water level fluctuation in these lakes may be 70 cm. The balance surveys for 2001–2002 indicate that anthropogenic changes related to mining and energy generation have a large effect on the water circulation in the catchments of these lakes.

4.2. The cyclicality of water level fluctuations in lakes

Skibniewski [1954] was one of the first researchers to investigate the issue of the cyclicality of water level fluctuations in lakes. On the basis of a long measurement series, he demonstrated the existence of this phenomenon in the lakes in the Masurian and Pomeranian Lake Districts. He determined the variable cycles (every

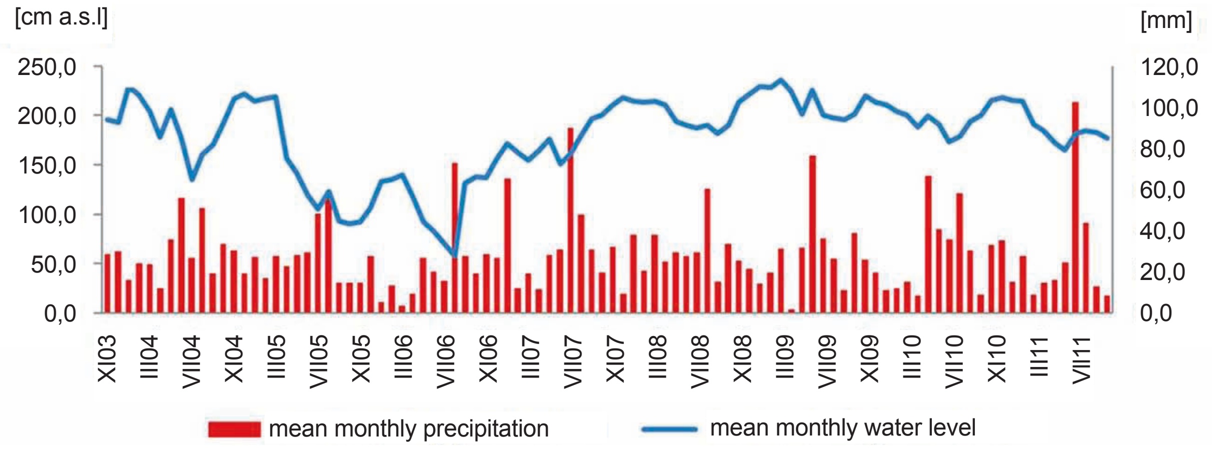


Fig. 1. Water level fluctuations in Lake Łękuk in 2003–2011 against mean monthly precipitation totals in its catchment
Source: Data from the Inspectorate for Environmental Protection within the National Environmental Monitoring System

12–19 years) on the basis of water level curves, adjusted by the gravimetric method.

On the basis of 100-year measurement series, Mikulski [1966] demonstrated, using the Fuhrich autocorrelation method, that the GMLs were characterised by 23-year cyclicality. His analysis of the series confirmed the tendency of the water levels in Polish lakes to fall, which had been observed by Skibniewski [1954]. Pasławski [1972] came to the same conclusions. On the basis of research on the cyclicality of natural water level fluctuations in 11 lakes with an outflow in Northern Poland, he also found a 23-year fluctuation rhythm. The measurement series covered both wet and dry years representing the extreme weather conditions.

Dąbrowski and Węglarczyk [2005] tried to carry out a contemporary assessment of the rhythm of the fluctuations in Polish lakes. For their research, they selected measurement series in 12 lakes situated within the area of the last glaciation. Using the Fourier spectral analysis, for the 95% tolerance limit, they did not find any periods when water levels recurred. Only when they had lowered the tolerance limit to 90% could they find that periods of 3–4 years, 6–7 years and 11–13 years could be distinguished in the natural water levels in lakes. The dominating fluctuation cycle was a 7-year period. Despite the fact that the tolerance limit had been lowered to 90%, 42% of lakes did not show any features of the cyclicality of fluctuations.

On the basis of mean monthly water levels in 10 lakes in the Podlaskie Province in 1961–1995, Górniak [2001] calculated that the value of the variation coefficient of the mean monthly water levels in the lakes fell within the interval of 17–44% for the period 1961–1995 and 14–42% for the period 1966–1995 (the analysis did not take into account the cases where the interval of the water levels was smaller than 30 cm). These values are close to the variation coefficients for the annual flows in rivers in North-eastern Poland. Lakes with a natural hydrological regime were characterised by the variability of mean water levels of the order of 18–25%, whereas lakes with an artificially altered regime had distinctly lesser variability of water levels. Lakes that function as retention reservoirs show a 2–3 times greater variability of water levels. Lakes Rajgrodzkie and Wigry are characterised by a fluctuation cycle of 21–22 years, while for Lake Hańcza this cycle is twice as long (54–55 years). The hydrological changes in Lake Białe caused by humans (its incorporation into the Augustów Canal system) have completely eliminated the entirely natural cycle of water table level fluctuations.

4.3. Trends in water table level fluctuations

The regression analysis of the annual precipitation totals and annual water levels in 1951–1998 that was carried out by Bajkiewicz-Grabowska [2001] for 21 lakes in North-eastern Poland did not show a statistically significant relationship between the features examined. In turn, the behaviour of the water table level fluctuations in lakes in the basins of the Pisa and Węgorapa Rivers was similar to that in the GML system. On the basis of an analysis of the mean annual water table levels in the following time series: 1951–1998, 1961–1998, 1971–1998 and 1981–1998, this author also indicated a steady growing trend in mean water levels in Lakes Nidzkie and Hańcza, in contrast to a falling trend in the other lakes (conspicuous particularly since the 1970s).

Using the simple regression method, for a set of 33 lakes (including 17 with a natural hydrological regime) in North-eastern Poland, Dąbrowski [2002] found a falling trend in water table level changes in flow-through lakes and a growing trend for lakes with an outflow. The same was stated [Dąbrowski 2004] in most of the lakes studied in Pomerania Lakeland (14 lakes with natural hydrological regime, 4 lakes under the influence of anthropogenic and 4 coastal lakes).

Explaining the causes of fluctuations in Lake Góreckie by means of regression, which took into account the independent variables for water stored in the Wielkopolska Buried Valley Aquifer, Kolendowicz et al. [2008] found that the water level in a lake depended primarily on the groundwater level in the Buried Valley Aquifer. The weather conditions also affected the variability of water levels in the reservoir (however, to a lesser degree than in the first case). They pointed out that there was no relationship between the monthly precipitation total and the water level.

Nowak and Grześkowiak [2010] presented in graphic form the water level fluctuations in lakes with hydro-engineering structures at their outflow (Fig. 2a Lakes Powidzkie and Lubikowskie) and lakes without these structures or with the structures failing to perform their functions (Fig. 2b Lakes Niesłysz and Sławskie).

Lake Sławskie, which is dammed-up by a weir on the Obrzyca, maintains an average water level despite high evaporation and has even slightly raised its water table level. The case of Lake Niesłysz, which is dammed-up by a dike, is similar. The situation of Lakes Powidzkie and Lubikowskie is completely different. The former of these lakes substantially depends on precipitation. The water table of this lake rose in wet years and fell in dry years. Such a situation had occurred until 1992 when the water table fell below the outflow. Ever since, a steady falling trend of the water table is observed. Over the years, Lake Lubikowskie depended on artificial water damming up. From the start of observations to 1998, a similar water level persisted. In 1998, the damming-up structure was destroyed and the lake began to rapidly lower its water level. In the survey period from 1976 to 2005, artificially dammed-up lakes were characterised by lower fluctuations (Lake Sławskie – 73 cm, Lake Niesłysz – 63 cm) than those in lakes without damming-up structures (Lake Powidzkie – 114 cm, Lake Lubikowskie – 141 cm).

Ilnicki and Orłowski [2006] analysed the lowering of the water table in the lakes in the Powidz Landscape Park. This negative process began in 1990. In 1992–1993, the lowest water levels in history were recorded, while in the period from 1994 to 1999 the water table rose again. Since 2000, the water table has been seen to sharply fall. This process was most conspicuous in Lakes Suszewskie and Wilczyńskie. The water table in these lakes has fallen by almost 3 m and in Lakes Budzisławskie and Ostrowskie by about 1.7 m. This sharp fall in the water level is attributed to climate change and underground drainage of open pits of the Konin Lignite Mine.

Konatowska and Rutkowski [2008] pointed out that the substantial lowering of the water level in Lake Kamińsko (the County of Poznań) and the reduction in the surface area of its water table by almost 50% over the last 150 years had probably been caused by two factors: the construction of a water intake at the village of Kamińsko and the connection of the lake with Lake Olechowskie by a series of ditches.

5. WATER LEVEL FLUCTUATIONS IN THE LIGHT OF THE ECOLOGICAL ASSESSMENT OF LAKES

Water level fluctuations in lakes are a natural feature that can be modified by human activities. Natural water level fluctuations are a necessary condition for the development of many species, thus contributing to maintaining biodiversity and controlling the functioning of an ecosystem [Coops et al. 2003, Leira and Cantonati 2008, Wantzen et al. 2008]. Interference with a natural cycle of water level changes can seriously disturb this functioning, preventing the reservoir from achieving good ecological status [Keto et al. 2008].

It follows from the survey carried out that natural annual water level fluctuations in Polish lowland lakes usually do not exceed

50 cm. They are greater in coastal lakes. In the case of many Polish lakes for which there are longer measurement series, the water levels are found to fall; the reasons for this are sought in both natural factors (e.g. the climate condition) and anthropogenic ones (e.g. the drainage of open pits). This phenomenon can also be seen in other countries [White et al. 2008, Du et al. 2011]. It can be assumed that many lakes continue to exist only because they are dammed-up.

The WFD requires an assessment of the intensity of hydromorphological alterations as an element supporting an ecological status assessment. One of the criteria for assessing hydromorphological alterations of lakes is the magnitude of water flow and dynamics, which is directly related to the water level fluctuations. If hydromorphological alterations are so strong (and, at the same time, cannot be eliminated for social and economic reasons) that they prevent the achievement of good ecological status in biological terms the water body subjected to such impacts should be designated as a heavily modified water body (HMWB). In such a case, the environmental objective is good ecological potential, which by definition is less rigorous than good ecological status.

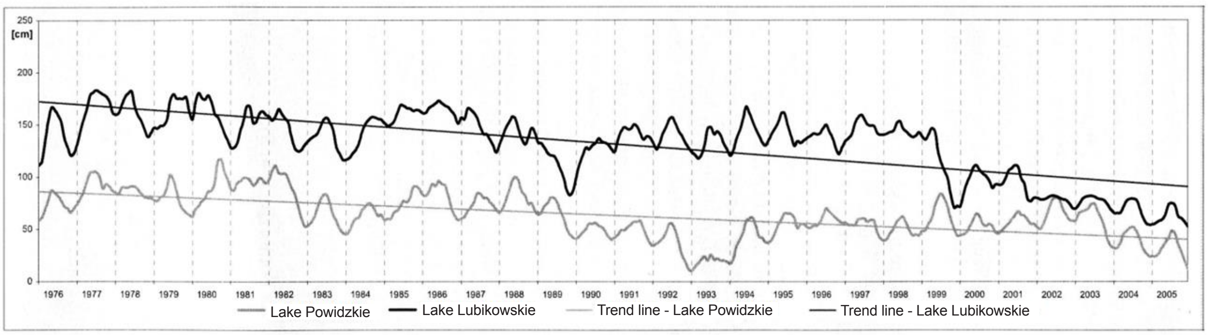
Therefore, an assessment of the impact of water level fluctuations in lakes on aquatic biota is a key element that warrants consideration of this criterion in the process of designating HMWB.

Although anthropogenic water level fluctuations in most Polish lakes seem to fall within the scope of natural fluctuations, in some cases economic activities (e.g. the use of lakes for energy generation purposes) may lead to strong disturbances of the hydrological regime causing an ecological instability of a reservoir [Zdanowski 1998] that makes it impossible to maintain/achieve good ecological status. However, in accordance with the methodology adopted in Poland for verifying the designation of heavily modified lake water bodies [Bedryj et al. 2011], the impact of hydromorphological alterations, including WLF, on biota is not considered in this process. In consequence, there are no premises for a correct description, in biological terms, of the environmental objective for HMWB, i.e. good ecological potential.

The issue of the impact of water level fluctuations on biota has been less well explored for lakes than for rivers [Coops et al. 2003, Wantzen et al. 2008, White et al. 2008]. It is stronger in shallow lakes than in deeper lakes [Coops et al. 2008, Leira and Cantonati 2008]. In the case of an assessment of the risk of deterioration of the ecological status of a lake as a result of water level changes, the UK Technical Advisory Group on the Water Framework Directive [WFD UK TAG 2012] recommends the standards relating to the maximum reduction in the lake area caused by these changes that lasts for a specific time. It is assumed that for shallow lakes good ecological status can be maintained when the water level falls to 40 cm and in the case of deep lakes even to 1.5 m.

It follows from the review articles on the impacts of water level fluctuations in lakes on biota [e.g. Zohary and Ostrovsky 2011, Leira and Cantonati 2008, Soszka et al. 2012] that macrophytes and littoral macroinvertebrates are considered a group of organisms that are most vulnerable to water level fluctuations. Many projects on the impact of water level fluctuations in lakes on organisms have been undertaken in Finland where about 30% of lakes are those with regulated water levels and the assessment of hydromorphological alterations, the development of measures to prevent their adverse ecological effects and the determination of the criteria for HWMB designation pose a significant challenge [Keto et al. 2008]. The outcomes of these projects include e.g. the *Regcel* computer model that enables an assessment of the impact of water level regulation in lakes on their biological elements (macrophytes, benthal

a)



b)

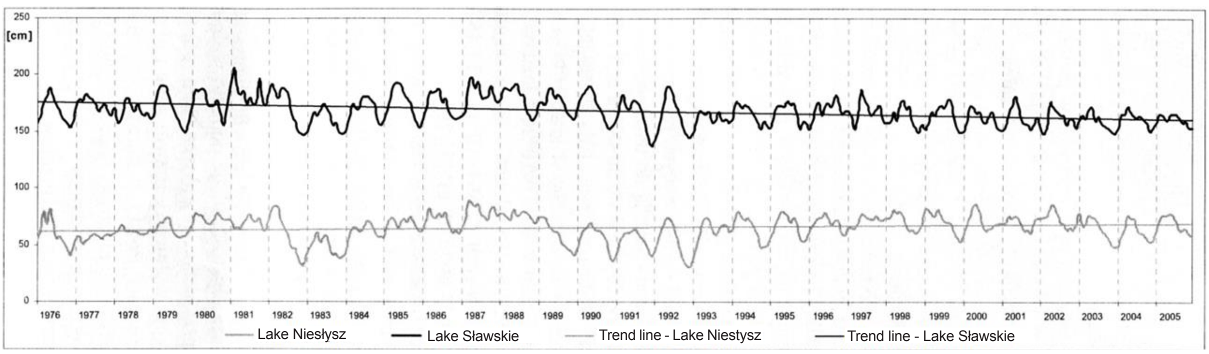


Fig. 2. Mean monthly water level fluctuations in: a) dammed-up lakes, b) undammed-up lakes in the 30-year period from 1976 to 2005
Source: Nowak and Grześkowiak 2010

invertebrates, fish and waterfowl) and their use for recreation purposes [Keto et al. 2008]. Using this tool, it was estimated that 20% of regulated lakes (out of 81 lakes analysed) represented high ecological status (their hydrological regime corresponded completely or almost completely to the natural conditions), while only about 20% of lakes with regulated water levels were classified on a preliminarily basis as HMWB, i.e. those that cannot achieve good ecological status and for which the environmental objective can only be good ecological potential. In this case, both the ecological status and ecological potential are expressed by the values of indicators calibrated for hydrological pressures. However, in general, there are no such indicators. Indeed, most biological methods for the assessment of ecological status that are applied in Europe are calibrated against eutrophication or organic pollution [Hering et al. 2010, Birk et al. 2012]. Such a situation also exists in Poland: the methods for the assessment of lakes on the basis of phytoplankton [Hutorowicz and Pasztaleniec in press], macrophytes [Kolada et al. 2011], phytobenthos [Picińska-Fałtynowicz 2011] and fish [Białokoz and Chybowski 2011] that have been implemented to date use metrics correlated only with trophy level indicators. The issue of the ecological impacts of water level fluctuations in lakes increasingly gains in importance in the light of the climate change observed and the need to adapt the water management principles to the change. This makes it necessary to expand the methods for assessing domestic lakes with new biological indicators designed for assessing the impact of hydrological alterations on biota.

REFERENCES AND LEGAL ACTS

ANDREEVA M. N. 1973. The long-term pattern in the level fluctuation of the Ural Lakes and its relationship with atmospheric circulation. Hydrology of Lakes, IAHS publ., 109: 176-181.

BAJKIEWICZ-GRABOWSKA E. 2001. Trends in water level changes in the lakes of North-estern Poland. Limnological Rev., 1: 3-14.

BAJKIEWICZ-GRABOWSKA E. 2005. Jeziora [in:] RICHLING A., OSTASZEWSKA K. (ed.) Geografia fizyczna Polski. PWN, Warszawa, p. 173-183.

BEDNARCZYK S., JARZĘBIŃSKA T., MACKIEWICZ S., WOŁOSZYN E. 2006. Vademecum ochrony przeciwpowodziowej. KZGW, Gdańsk.

BEDRYJ M., BŁACHUTA J., BRODZIŃSKA B., GRZEŚKOWIAK A., NOWAK B., ŻAK J. 2011. Opracowanie metodyki weryfikacji wyznaczania silnie zmienionych i sztucznych części wód jeziornych. IMGW-PIB, Poznań.

BENDEFY L. 1973. Relation existing between the periodic fluctuation of the water levels of the Hungarian lakes and solar activity. Hydrology of Lakes, IAHS publ., 109: 109-114.

BIAŁOKOZ W., CHYBOWSKI Ł. 2011. 5. Ichtiofauna [in:] SOSZKA H. (ed.) Ocena stanu ekologicznego wód zlewni rzeki Wel. Wytyczne do zintegrowanej oceny stanu ekologicznego rzek i jezior na potrzeby planów gospodarowania wodami w dorzeczu. IRŚ, Olsztyn, p. 217-234.

BIELAKOWSKA W. No date. Retencjonowanie wód - mała retencja wodna. Access protocol: http://www.ekoportal.gov.pl/opencms/opencms/ekoportal/prawo_dokumenty_strategiczne/ochrona_srodowiska_w_polsce_zagadnienia/Woda/retencja_wodna.html#__Retencja23 [19 October 2012].

BIRK S., BONNE W., BORJA A., BRUCET S., COURRAT A., POIKANE S., SOLIMINI A., VAN DE BUND W., ZAMPOUKAS N., HERING D. 2012. Three hundred ways to assess Europe's surface waters: An almost completeoverview of biological methods to implement the Water Framework Directive. Ecological Indicators, 18: 31-41.

BOROWIAK D. 2000. Reżimy wodne i funkcje hydrologiczne jezior Niżu Polskiego. Ser. Bad. Limnol. 2, Wyd. KLUG, Gdańsk.

CHLOST I., CIEŚLIŃSKI R. 2005. Change of level of waters Lake Łebsko. Limnological Rev., 1: 17-26.

CHOIŃSKI A. 1985. Wybrane zagadnienia z limnologii fizycznej Polski. Wyd. Nauk. UAM., Poznań.

CHOIŃSKI A. 2000. Jeziora Kuli Ziemskiej. PWN, Warszawa.

CHOIŃSKI A. 2007. Limnologia fizyczna Polski. Wydawnictwo Naukowe UAM., Poznań.

CIEPIELOWSKI A. 1999. Podstawy gospodarowania wodą. Wydawnictwo SGGW, Warszawa.

COOPS, H., BEKLIOGLU M., CRISMAN T. L. 2003. The role of water-level fluctuations in shallow lake ecosystems - Workshop conclusions. Hydrobiologia, 506–509: 23–27.

DĄBROWSKI M. 2001. Anthropogenic changes in the hydrographic system of Great Mazurian Lakes. Limnological Rev., 1: 49-56.

DĄBROWSKI M. 2002. Changes in the water level of lakes northeastern Poland. Limnological Rev., 2: 85-92.

DĄBROWSKI M. 2004. Trends in changes of lake water levels in the Pomerania Lakeland. Limnological Rev., 4: 85-92.

DĄBROWSKI M., WĘGLARCZYK S. 2005. Cyclical nature of fluctuations in the levels of lakes of Northern Poland. Limnological Rev., 5: 61-67.

DU Y., XUE H.P., WU S.J., LING F., XIAO F., WEI X.H. 2011. Lake area changes in the middle Yangtze region of China over 20th century, J. Environ. Manage., 92(4): 1248-1255.

EU 2000. Directive 2000/60/EC of the European Parliament and of the Council of 23 Oct. 2000 establishing a framework for Community action in the field of water policy. OJEC L 327/1 of 22.12.2000.

GÓRNIAK A. 2001. Natural and anthropogenic changes in the water level of lakes of the Podlaskie Voivodeship. Limnological Rev., 1: 125-130.

HERING D., BORJA A., CARSTENSEN J., CARVALHO L., ELLIOTT M., FELD C.K., HEISKANEN A.S., JOHNSON R.K., MOE J., PONT D., SOLHEIM A.L., VAN DE BUND W. 2010. The European Water Framework Directive at the age of 10: a critical review of the achievements with recommendations for the future. Science of the Total Environment, 408: 4007–4019.

HUTOROWICZ A., PASZTALENIEC A. In Press. Description of the Phytoplankton Metric of ecological status assessment for Polish Lakes and its performance along nutrient gradients. Pol. J. Ecol.

ILNICKI P., ORŁOWSKI W. 2006. Klęska ekologiczna w Powidzkim Parku Krajobrazowym, Aura, 10: 11-14.

JAŃCZAK J. 1991. Fizycznogeograficzna typologia i ocena jezior na przykładzie Pojezierza Wielkopolskiego. Materiały Badawcze IMGW, Seria: Hydrologia i Oceanologia 15.

JAŃCZAK J. (ed.) 1996-1999. Atlas jezior Polski. Tom I–III. IMGW, Oddział w Poznaniu, Wydawnictwo Naukowe Bogucki.

JEZNACH J. 1999. Ekspertyza hydrologiczno-przyrodnicza jeziora Zgorzała wraz z oceną wpływu sposobu zagospodarowania obszaru na jego prawidłowe funkcjonowanie, Zespół Rzeczoznawców Inżynierów i Techników Wodnych i Melioracyjnych. Warszawa (not published).

KANCLERZ J., MURAT-BŁAŻEJEWSKA S., SOJKA M. 2007. Zmienność stanów wody w jeziorach położonych w zlewni Małej Wełny. Materiały Ogólnopolskiej Konferencji Naukowej „Kompleksowe i szczegółowe problemy inżynierii środowiska", Darłówko, p. 695-705.

KETO A., TARVAINEN A., MARTTUNEN M., HELLSTEN S. 2008. Use of the water-level fluctuation analysis tool (Regiel) in hydrological status assessment of Finnish lakes. Hydrobiologia, 613: 133-142.

KOLADA A., CIECIERSKA H., RUSZCZYŃSKA J., MJELDE M., DZIEDZIC J., DYNOWSKI P., JASNORZEWSKI A. 2011. 2. Makrofity [in:] SOSZKA H. (ed.) Ocena stanu ekologicznego wód zlewni rzeki Wel. Wytyczne do zintegrowanej oceny stanu ekologicznego rzek i jezior na potrzeby planów gospodarowania wodami w dorzeczu. IRŚ, Olsztyn, p. 169-186.

KOLENDOWICZ L., HAUKE J., KACZMAREK L., LORENC M. 2008. Zmiany poziomu wody Jeziora Góreckiego (Wielkopolski Park Narodowy) w latach 2002-2007 na tle wahania poziomu wód wielkopolskiej doliny kopalnej i warunków atmosferycznych. [in:] PARTYKA J., POCIASK-KARTECZKA J. (ed.) Wody na obszarach chronionych. Instytut Geografii i Gospodarki Przestrzennej UJ, Ojcowski Park Narodowy, Komisja Hydrologiczna PTG, Kraków, p. 159-168.

KONATOWSKA M., RUTKOWSKI P. 2008. Zmiany powierzchni i poziomu lustra wody jeziora Kamińsko (Nadleśnictwo Doświadczalne Zielonka) na przestrzeni ostatnich 150 lat. Studia i Materiały Centrum Edukacji Przyrodniczo-Leśnej R. 10. Zeszyt 2: 205-217.

LECH J. J. 2006. Zasada działania oraz wpływ na środowisko elektrowni szczytowo-pompowej w Żarnowcu. Access protocol:: www.ekoportal.eu/Artykuly/Zasada_dzialania_oraz_wplyw_na_srodowisko_elektrowni_szczytowo-pompowej_w_Zarnowcu/strona-2.html [27 August 2012].

LEIRA M., CANTONATI M. 2008. Effects of water-level fluctuations on lakes: an annotated Bibliography. Hydrobiologia 613: 171–184.

MARKS L. 1992. Osady i formy rzeźby jeziornej i bagiennej. [in:] LINDNER L. (ed.) Czwartorzęd, osady, metody badań, stratygrafia, Wydawnictwo PAE, Warszawa, p. 242-273.

MICHALCZYK Z., TURCZYŃSKI M. 2001. Lake-levels and solar activity. Limnological Rev., 1: 207-212.

MICHALCZYK Z., CHMIEL S., TURCZYŃSKI M. 2011. Lake water stage dynamics in the Łęczna-Włodawa Lake District in 1991-2010. Limnological Rev., 11: 113-122.

MIKULSKI Z. 1963. Zarys hydrografii Polski. PWN, Warszawa.

MIKULSKI Z. 1966. Bilans wodny Wielkich Jezior Mazurskich. PIHM, Warszawa.

MIKULSKI Z. 1970. Kształtowanie się bilansu wodnego jezior w Polsce. Przegl. Geogr., t. 42, nr 3.

NOWAK B., GRZEŚKOWIAK A. 2010. Ocena skutków piętrzenia jezior jako element wstępny opracowania modelu rewitalizacji jezior województwa wielkopolskiego, [in:] MOŃKA B. (ed.) Zarządzanie zasobami wodnymi w dorzeczu Odry, Wydawnictwo PZITS nr 894, Wrocław, p. 271-280.

NOWICKA B. 2003. Impact of Charzykowskie Lake on water upliffing in Seven Lakes Stream. Limnological Rev., 3: 173-180.

PASŁAWSKI Z. 1972. Wieloletnie wahania i tendencje zmian poziomu wód jezior odpływowych w Polsce Północnej. Przegląd geofizyczny, XVII: 249-259.

PASŁAWSKI Z. 1975. Typologia hydrologiczna jezior Pojezierza Wielkopolskiego. Przegląd Geofizyczny, XX: 271-280.

PASŁAWSKI Z. 1988. Charakterystyka hydrologiczna Jeziora Góreckiego i zasoby wodne Wielkopolskiego Parku Narodowego. [in:] DAMBSKA I., BAŁAZY S., PAWUŁA R. (ed.) Wielkopolski Park Narodowy. Problemy ochrony i kształtowania środowiska przyrodniczego, PWN, Warszawa-Poznań, p. 45-53.

PICIŃSKA-FAŁTYNOWICZ J. 2011. 3. Fitobentos [in:] SOSZKA H. (ed.), Ocena stanu ekologicznego wód zlewni rzeki Wel. Wytyczne do zintegrowanej oceny stanu ekologicznego rzek i jezior na potrzeby planów gospodarowania wodami w dorzeczu. IRŚ, Olsztyn, p. 187-202.

PIETKIEWICZ S. 1958. Wody kuli ziemskiej. Wody Lądowe, PWN, Warszawa.

RÖSLER A. 2000, Bilans wodny Jeziora Sławskiego [in:] WOJCIK G., MARCINAIK K. (ed.) Funkcjonowanie i monitoring geoekosystemów z uwzględnieniem lokalnych problemów ekologicznych, Zeszyty Naukowe Komitetu Człowiek i Środowisko przy prezydium PAN vol. 25, Warszawa, p. 191-200.

RUREK M. 2008. Lokalne zmiany środowiska przyrodniczego wywołane działalnością bobra europejskiego (*castor fiber* L.) w okolicy Trzebcin (powiat tucholski) [in:] BABIŃSKI Z. (ed.), Promotio Geographica Bydgostiensia. Wydawnictwo UKW, Bydgoszcz, p.119-128.

Regional Water Management Authority in Warsaw. 2012. Wielkie Jeziora Mazurskie. Access protocol: www.warszawa.rzgw.gov.pl/lewe_menu-utrzymanie_wod_i_urzadzen_wodnych wykaz_administrowanych_obiektow-system_jezior_mazurskich.html [30 August 2012].

SKIBNIEWSKI L. 1954. Wahania Poziomów zwierciadła wody większych jezior Pojezierza Pomorskiego i Mazurskiego. Prz. Met. Hydr., 7: 159-172.

SKOWRON R. 2002. Hydrological changes caused by water damming in the lower stretch of the Skarlanka river as exemplified by Lake Bachotek. Limnological Rev., 2: 373-380.

SOSZKA H., PASZTALENIEC A., KOPROWSKA K., KOLADA A., OCHOCKA A. 2012. Wpływ przekształceń hydromorfologicznych jezior na zaspoły organizmów wodnych – przegląd piśmiennictwa. Ochrona Środowiska i Zasobów Naturalnych, 50: 24-52.

SZRAMKA R., RÓŻYCKI A. W. 1999. Perspektywy dla małych elektrowni wodnych. Biuletyn URE 4/1999.

SZIWA R., JAŃCZAK J., KOWALIK A., BRODZIŃSKA B. 2003. Lake water level fluctuation and hydrological balance of Konin lakes in heavy anthropopressure condinations. Limnological Rev., 3: 243-248.

WANTZEN K.M., ROTHHAUPT K.O., MÖRTL M., CANTONATI M., TÓTH L.G., FISCHER P. 2008. Ecological effects of water-level fluctuations in lakes: an urgent issue. Hydrobiologia, 613: 1-4.

WFD UK TAG. 2012. Updated Recommendations on Environmental Standards. River Basin Management (2015-21). Draft SR3 – 2012.

WHITE M. S., XENOPOULOS M. A., HOGSDEN K., METCALFE R. A., DILLON P. J. 2008. Natural lake level fluctuation and associated concordance with water quality and aquatic communities within small lakes of the laurentian great lakes region. Hydrobiologia, 613: 21-31.

ZDANOWSKI B. (ed.) 1998. Jeziora konińskie – 40 lat badań. Stan aktualny oraz wnioski dla ochrony. Państwowa Inspekcja Ochrony Środowiska, Wojewódzki Inspektorat Ochrony Środowiska w Koninie. Biblioteka Monitoringu Środowiska, Konin, p. 124.

ZOHARY T., OSTROVSKY I. 2011. Ecological impacts of excessive water level fluctuations in stratified freshwater lakes. Inland Waters, 1(1): 47-59.