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The effect of a water dam on Lake Powidzkie and its vicinity

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Abstract. The paper presents an attempt to assess the effect of damming of lakes on water resources, based on the example of Lake Powidzkie (Central Poland) and its catchment. The region in which the analysed object is located has the greatest water deficits in Poland. The co-occurrence of unfavourable natural and anthropogenic factors contributed to a considerable reduction in the water resources retained in the lake. Particularly low water levels were recorded in the 1990s and in the first decade of the 21st century. The situation was not improved by a water dam constructed on the outflow from the lake in the 1960s, due, among other things, to neglect in its exploitation. With regard to the modernisation of the dam in 2010 and the favourable hydrological situation in the winter of 2011, it was possible to retain the excess water and substantially reduce its outflow. The restoration of the lost water resources, and the hydrological benefits of this were still observable several years later. Problems related to water deficits are becoming increasingly common in many regions of the world. One solution to mitigate such a situation may be, among others, to dam natural lakes. This is simpler, cheaper, and less invasive for the environment than the construction of new water reservoirs.

Key words:
hydrotechnical works,
dammed lake,
water resources,
Powidzkie Lake

Introduction

Changes in the natural environment are being observed in many processes in particular systems of the geosphere. For many reasons (both natural and economic), it is important to reduce the dynamics of such processes. In the case of the hydrosphere, it is vital to control extreme situations, i.e. those related to deficits or excesses of water. In the context of water balance, such a role is ascribed to water retention (Ptak 2015). Among surface waters, lakes have the greatest potential for water retention. Due to their possibility of water retention, lakes constitute a key element in the existence and development of many areas of economy (energy engineering, agriculture, tourism, etc.). Due to the aforementioned conditions, lakes are becoming an important factor in determining the course of natural processes, as well as in the economic development of a given area. In regions with no natural lakes, artificial reservoirs are constructed. In the conditions of scarce water resources occurring in Poland, it is important to slow the transformation of precipitation into runoff in order to make changes in the elements of the water balance possible. The lowest values of unitary runoff of <2.5 $dm^3 \cdot s^{-1} \cdot km^{-2}$ occur in, among others, the region of Wielkopolska and Kujawy (Hydrological

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Atlas … 1987). Due to this, it is important to adapt the environmental conditions to increase water resources in the region to the greatest possible degree. Such assumptions are implemented through the construction of dams on rivers, construction of artificial water reservoirs, and damming of the natural lakes, among others. Such measures resulted in an increase of 84.7 million m^3 in the volume of retained water nationwide, while most of that (39 million m^3) was obtained by damming lakes (Kowalewski et al. 2002).

The objective of the paper is to assess the functioning of the water dam at the outflow of Lake Powidzkie with regard to the lake itself as well as to the environmental, hydrological, and economic conditions in its vicinity.

Study object

Powidzkie Lake

Lake Powidzkie is located in central Poland (Fig. 1). According to the physical-geographical division, it is located in the subregion of the Gnieźnieńskie Lakeland (Kondracki 2009). It is the largest lake in the Wielkopolska region, with a surface area of 1,078.0 ha and maximum depth of 47.0 m (Nowak in press). Moreover, the lake is connected to Lake Powidzkie Małe (Fig. 1) via a narrow isthmus. Lake Powidzkie Małe is a former fragment of a larger water body. The combined surface area of both lakes is 1,132.0 ha. In hydrographic terms, the analysed object belongs to the catchment area of the Meszna River, a left-bank tributary of the Warta River. The Meszna has its origin in the southern edge of the water body. The lake has several small tributaries. The largest of them include: inflow from Lake Kosewskie, Struga Powidzka River, and the ditches Rów Smolnicki and Rów Ostrowski. Total discharges in the streams do not exceed several tens of litres per second (Nowak and Mielcarek 2016).

Water dam on Lake Powidzkie

A water dam is located on the outflow from Lake Powidzkie. It was constructed in 1963, and modernised in 2010 (Fig. 2). The construction of the dam was intended to stabilise the water level in Lake Powidzkie and create an additional water reserve which could be used to supplement water deficits in the Słupecki Reservoir below, for agricultural irrigation, fishery, and recreational purposes.

According to the Manual … (2014), the elevation of the edge of the dam is 98.00 m a.s.l. (Baltic). The minimum ordinate of the water level is 98.20 m a.s.l, and the maximum water level reaches 98.80 m a.s.l. The maximum volume at the high water level ordinate of 98.80 m a.s.l. is 1,367,000 m^3, and the minimum is 1,294,000 m^3 (at an ordinate of 98.20 m a.s.l.). The thickness of the manipulation layer is 0.6 m, and its volume is more than 7.3 million m^3. The opening of the dam is 3.4 m^2.

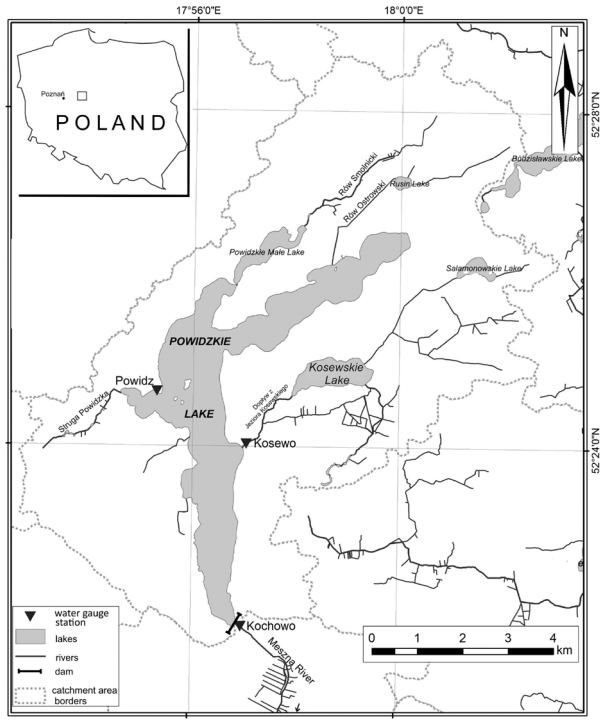

Fig. 1. Location of the study area

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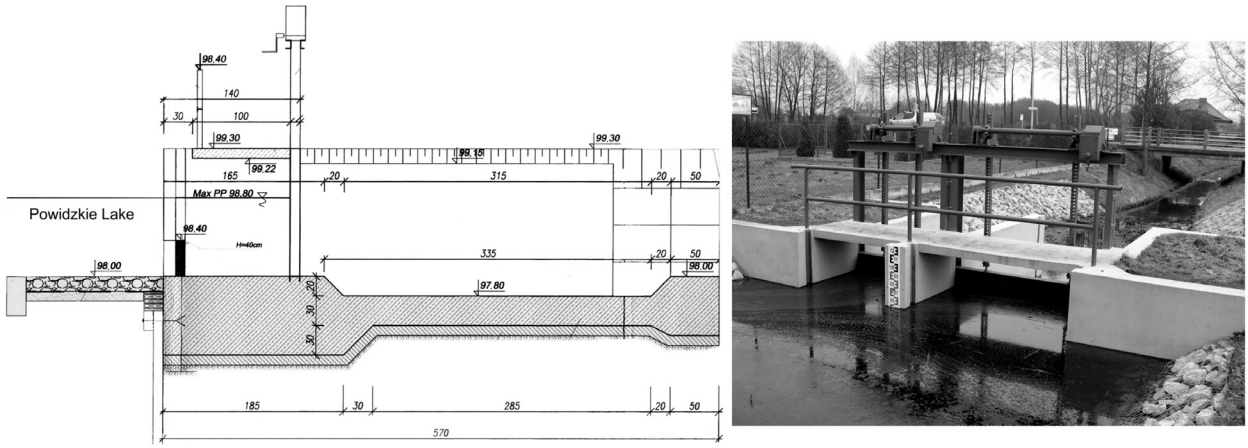

Fig. 2. Structure of the dam on the outflow from Lake Powidzkie

Methods

The study is based on data obtained from the measurement–observation network of the Institute of Meteorology and Water Management – National Research Institute (IMGW-PIB), the National Geological Institute – National Research Institute (PIG-PIB), State Forests Holding, and the authors' own monitoring network established as part of a project financed by the National Science Centre (UMO-2011/03/N/ST10/05014). These include hydrological, meteorological, and hydrogeological data. Technical data containing information on the hydrotechnical facility on the outflow of Lake Powidzkie were obtained from the Wielkopolska Board of Land Facilities and Water Management, which administers the object. The collected materials permitted the assessment of the climatic and hydrological background of the discussed region, and the role of the lake in determining changes in hydrological conditions.

Results and discussion

Melioration works initiated in the 1950s in the analysed region, combined with low precipitation, impoverished the water resources in the vicinity of Lake Powidzkie. Measures aimed at reducing the aforementioned effects included the construction of a dam on the outflow of Lake Powidzkie, and the possibility of manipulating water retention. With the perspective of time, the water level fluctuations in Lake Powidzkie (Fig. 3) have shown that for many reasons such measures were difficult to implement.

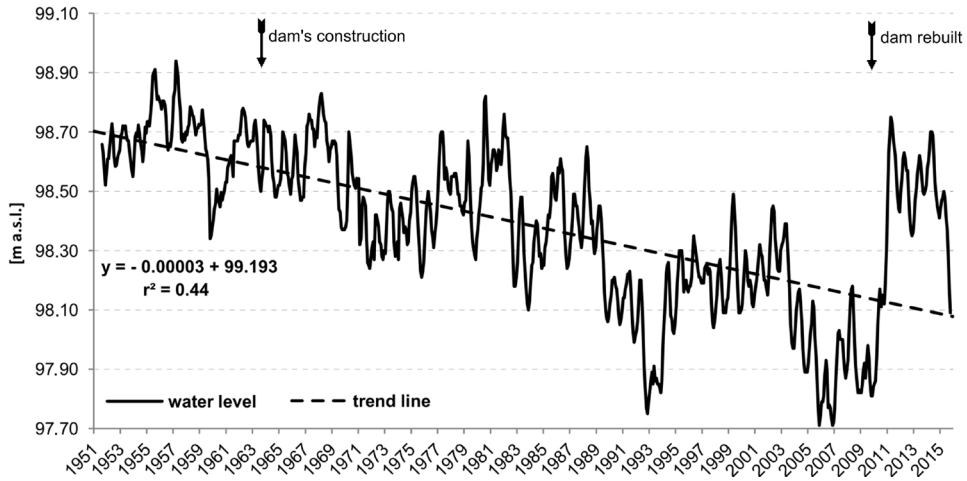

Fig. 3. Mean monthly water stages in Lake Powidzkie in the period 1951-2015 (source: Nowak in press, changed)

Successive impoverishments of the water resources in the discussed catchment resulted in a decrease in the water level in the lake, and consequently a lack of outflow of the Meszna River from the lake in many years. Considering that the edge of the dam is located at 98.00 m a.s.l., the lack of hydraulic contact occurred among others in the 1990s, and in the period 2005–2010. Considering the minimum level of water level fluctuations (98.20 m a.s.l.), the period is extremely prolonged, thus making it impossible to manipulate the water resources of Lake Powidzkie. Water deficit periods in the region were determined by several co-occurring factors. They include climatic factors (Kędziora 2008; Stachowski et al. 2016), mining meliorations of the nearby opencast brown coal mines (Ilnicki 1996; Ilnicki and Orłowski 2006; Orłowski and Ilnicki 2007), groundwater intake in the catchment, and meliorations leading to over-drying of the area (Nowak in press; Przybyłek and Nowak 2011). In addition to the unfavourable meteorological–hydrological background, improper water management on the water dam on the lake should be emphasised (Przybyłek and Nowak 2011; Nowak and Gezella-Nowak 2012). Due to the state and functioning of the dam, a decision was taken to modernise it, which was carried out in 2010. The modernisation co-incided with very high precipitation in the area. In winter 2011, there was more than 300 mm of rain and snowfall (data of IMGW-PIB), leading to many flood events in the Wielkopolska and Kujawy regions (Nowak 2016). Discharges in streams feeding Lake Powidzkie reached the highest recorded values in the history of regular measurements (Nowak and Mielcarek 2016; Nowak *in press*). Due to this, Lake Powidzkie very rapidly began regaining water resources lost in previous years. Within half a year, the water level in the lake increased by more than 0.6 m, and within a year by 0.9 m, which had never happened before. Such an increase would not have been possible if not for the water dam closing the outflow. Limited water outflow from the lake was maintained for the following four years with small exceptions while the river channel was being cleaned, during the spring eel harvest, and while the Słupiecki Reservoir located below was being filled. Mean water runoff from the lake for the years was 0.021 $m^3 \cdot s^{-1}$ whereas in the period 2006–2010 it was practically nil. Without the dam, excess water would have rapidly discharged into the open channel of the Meszna River. Within several months of the high water stages, low stages would have occurred again. The effect of the dam on discharges in the Meszna River is presented in the course of discharges of the river in the Kochowo profile (Fig. 4), located 30 m below the hydrotechnical facility.

Discharge measurements performed with the smaller weir open during the highest stages in the lake were 0.386 $m^3 \cdot s^{-1}$. It can be assumed that unblocking both of the weirs would result in a discharge of 1.0 $m^3 \cdot s^{-1}$. The discharge would obviously rapidly decrease as a result of a systematic decrease in the water level in the lake and a decrease in the hydraulic gradient. Lack of damming in conditions of limited water supply to the lake would probably

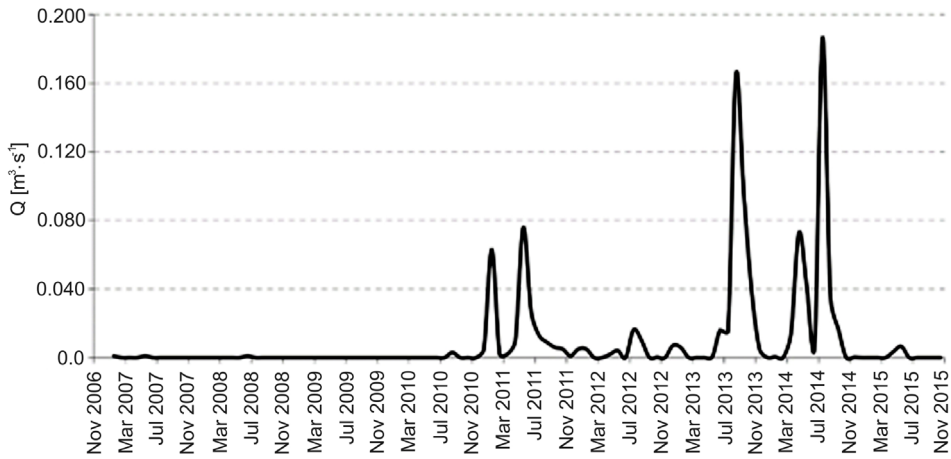

Fig. 4. Mean monthly discharges in the water gauge profile Kochowo on the Meszna River in the period 2006-2015 (source: Nowak *in press*, changed)

have led to low water stages in the lake by autumn 2011.

The issue of increases in water resources as a result of damming of lakes is popular among many researchers (Jańczak et al. 2001; Jańczak et al. 2004; Grześkowiak et al. 2012). Damming lakes has many positive as well as negative effects for the functioning of lake ecosystems. Sojka et al. (2010) emphasise that damming lakes is one of the basic directions of development for a catchment with lakes in order to meet users' needs for water resources. In analysing the example of Lake Bachotek, Skowron (2002) observed that hydrotechnical works on the lake contributed to stabilising water level fluctuations. Alongside similar conclusions for selected lakes of western Poland, Nowak and Grześkowiak (2010) also point to the high importance of damming lakes in the process of their revitalisation.

The detailed hydrological monitoring and field inventory revealed many benefits related to hydrotechnical regulations on Lake Powidzkie. Based on the example of the quite atypical year 2011 (atypical in terms of precipitation) and the following years, it is possible to trace in detail how water damming affected the lake and its surroundings. Damming and rational manipulation of water outflow from the lake not only contributed to the restoration of water resources in the lake, but also allowed high water stages to be prolonged, and guaranteed the maintenance of undisturbed flow rate in the Meszna River until the end of 2014. Complete blocking of the outflow from the lake in winter 2011 excluded the upper parts of the Meszna River catchment from the circulation. This reduced the possibility of occurrence of floods in its lower course, and considerably reduced the amount of water supplied by the river to the Warta River during high water stages. Together with water retention in the Słupecki Reservoir, located in the middle course of the Meszna River, damming Lake Powidzkie was in accordance with the anti-flood policy of the region of the middle Warta River. The retained water poured over the shallowest parts of the lake, filling its former basin. This resulted in an increase in the living space of organisms inhabiting the littoral zone, which had been reduced in earlier years. The phenomenon proved very favourable for fish, particularly those preferring to spawn in shallow zones of the supralittoral. An increase in the water level of the lake also contributed to the dying off of vegetation in the near-shore belt. This temporarily inhibited the process of overgrowing of the shore. This statement is based on visual observations and research on plants in several tens of transects performed both from land and water.

Stabilisation of the water level in the lake also translated into an increase in groundwater retention, and improved water relations in the catchment. The high water level in the lake reduced the hydraulic gradient in aquifers drained by the lake. This resulted in considerable slowing down of water outflow from aquifers I and II towards the lake, particularly in the zone of near-shore meadows and flat shores. The effect of the process was the development of post-snowmelt floods on the near-shore meadows previously unencountered since the 1980s, the restoration of small water bodies in the vicinity of the lake, and an increase in the water level in such water bodies. In the case of deeper aquifers, this caused a temporary reversal of water flow during the peak water stage periods in the lake (Fig. 5). The research applied results obtained from a network of water gauges, piezometers, and research wells, both the authors' own and institutional (IMGW-PIB and PIG-PIB).

Therefore, damming the lake considerably contributed to the improvement in groundwater resources in the region.

An increase in groundwater retention caused by high precipitation and damming of Lake Powidzkie also positively affected forests and other vegetation in the belt where hydroisobaths occur in the range of 1–2.5 m below ground level. The increase in water level was most evident within this range. On the other hand, it did not cause complete flooding of the root system of trees. High levels of groundwater maintained throughout the year made it easily available to plants in hot and dry periods. Due to this, even on exceptionally hot summer days in the years 2011–14, vegetation overgrowing the areas remained in good condition, unlike in previous years. These conclusions are based on expert opinion confirmed by foresters and farmers from the analysed area.

The primary threats concerning regulation of the water level in lakes are related to the quality of their waters. According to Koc et al. (2005), flooding of the areas may be related, among others, to transition of biogenes and organic compounds from soils to

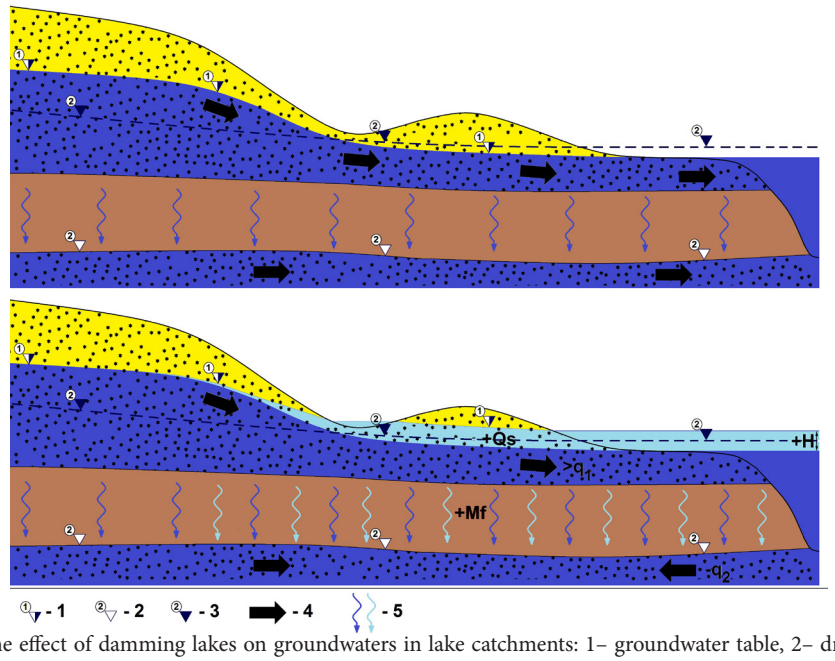

Fig. 5. Diagram of the effect of damming lakes on groundwaters in lake catchments: 1– groundwater table, 2– drilled water table of confined aquifer, 3– stabilised water table of confined aquifer, 4– direction of flow of groundwaters, 5– direction of infiltration, +H– increase in the water level in the lake, $+Q_s$– increase in statistical resources in the catchment, +Mf– increase in filtration to deeper aquifers, $>q_1$– decrease in unitary groundwater inflow to the lake, $-q_2$– reversal of the direction of groundwater flow in deeper aquifers (source: Nowak *in press*)

waters in amounts which can considerably disturb the lake's ecosystem through the rotting processes of plant and animal remains, and anaerobic decomposition of organic compounds which can supply toxic substances to the water. According to Gołdyn (1990), the primary threat related to damming lakes relates to the supply of products of decomposition from the littoral zone of the lake to the pelagial, causing an increase in its fertility. Similar effects, i.e. a decrease in the quality of water, are mentioned by Burchardt et al. (1994) based on the example of Lake Łęgowskie near Wągrowiec in the Wielkopolska Region.

In terms of water quality, damming of waters proved temporarily unfavourable to Lake Powidzkie. An increase in the water level in the lake caused flooding of near-shore zones which had been emergent for many years. Trees and other plants growing there, for which the transitional zone between land and water is the natural environment, began dying off as a result of the development of parameters typical of an aquatic environment. After several months, organic matter which had accumulated in the zone began to rot. This contributed to an increased supply of biogenic substances to the lake. Due to the depth of the lake and high volume of accumulated water, and therefore a high potential for dissolving pollutants, the situation can be considered as temporary.

Another effect of artificial regulation of water levels in lakes is the possibility of erosion processes intensifying in shore zones. When the water level is maintained within natural fluctuations, no substantial transformations should be expected. The situation is different if a lake shore which is exposed by a long-term decrease in water level has been subject to artificial development. Then, erosion processes can be more impulsive, as with artificial dam reservoirs, for example, where landslides frequently occur (Banach et al. 2013). In the case of Lake Powidzkie, there was artificial interference in the shoreline within the promenade running along the lake in the vicinity of Powidz, among other places. The promenade was entirely built on backfilled material distributed within the former lake bottom, and was dominated by organic soils. In the places most exposed to wave action, the base of the promenade was washed out during high water stages in the lake. This also revealed shortcomings in its hardening and securing against washing out.

In spite of the existence of certain unfavourable circumstances, as presented above, the increase and stabilisation of water resources accumulated in the lakes is favourable in terms of improving

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water balance. Many factors can cause a decrease in the water level in lakes, as described in detail by numerous analyses (Ptak et al. 2013; Bonacci et al. 2015; Choiński et al. 2016; Wrzesiński and Ptak 2016; Ptak et al. 2017; Skowron and Jaworski 2017; Volchak et al. 2017). In the context of the observed climate changes, activities aimed at water retention in the catchment will be of increasing importance. Due to the above, it is justified to develop hydrotechnical infrastructure on lakes, permitting retention of water during periods of excess, and manipulation of outflow in situations of low water level. It should be emphasised that manipulation should be performed within the range of natural water level fluctuations, therefore restoring the previous state, as in the case of the discussed lake. Moreover, it should be emphasised that damming natural lakes is a simpler and cheaper solution which is less invasive for the environment than the construction of new water reservoirs.

Conclusions

Problems with water deficits are increasingly common in many regions of the world. In central Poland, mean unitary outflow is 2.5 $dm^3 \cdot s^{-1} \cdot km^{-2}$ (Hydrological Atlas … 1987). Lake Powidzkie discussed in this paper is located there. In the case of this lake, water deficits are evident in the course of water level fluctuations, which substantially decreased over several decades. The modernisation of the water dam on the outflow of the Meszna River from Lake Powidzkie and its proper management allowed the lost resources to be restored. This co-incided with exceptionally favourable natural conditions in the form of high precipitation in 2011.

The retention capacity of Lake Powidzkie is several million cubic metres of water, in accordance with the water-legal permit covering the exploitation of the weir located at its outflow. This is therefore a considerable amount in terms of improving water relations in its catchment, but also in the broader scope of this part of the Wielkopolska region. The obtained available resources are accessible for agriculture, forestry, and other areas of the economy, which is very important in Poland's increasingly frequent periods of meteorological drought.

Assuming that water deficits in Lake Powidzkie are partially determined by human activity, it is particularly justified to dam the lake, and to minimise the effects of previous decisions which were inappropriate in terms of hydrology and water management.

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