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WATER STORAGE IN ANTHROPOGENIC LAKES IN SOUTHERN POLAND DURING HIGH AND LOW WATER STAGES

RETENCJA WODY W JEZIORACH ANTROPOGENNYCH POŁUDNIOWEJ POLSKI W OKRESIE WEZBRAŃ I NIŻÓWEK

Abstract: The central part of southern Poland is a land of anthropogenic lakes. Within an area of 6,766 km^2 as many as 4,773 water bodies are present with a total area of 185.5 km^2. Around a dozen of the largest water bodies serve flood protection purposes and are sources of water for municipal, industrial, agricultural, transport, energy purposes, etc. Such usage of these water bodies is the main reason for fluctuations in their water levels, although obviously these also depend directly on their supply (rainfall, groundwater drainage, water transfers), and indirectly on the size of their catchment areas and the degree to which their basins are full. The most spectacular changes in water levels occur during high and (less frequent) low water stages. Periodical rises in water levels related to high water episodes caused by thawing or rainfall reach as much as several metres compared to the period preceding the high water episode. Drought periods result in the lowering of storage levels towards minimum ones as does similarly the intentional discharge of water from reservoirs. In water bodies in southern Poland, annual changes in water levels range from several centimetres to almost ten metres. The variability of levels is often similar to the average depth of the water body in question, in some cases approaching its maximum depth. It determines the changes in the water retention, unprecedented for natural lakes.

Keywords: lake district, Upper Silesian region, water bodies, water storage, water level

Introduction

The economic development of the central part of southern Poland has resulted in the formation of a new anthropogenic lake district with an area of 6,766 km^2. The 4,773 water bodies within this lake district have different origins resulting from varied human activity. They were built for specific purposes, formed as a result of land reclamation measures or emerged spontaneously through anthropogenic transformation of the environment. The total area of the water bodies present within the Upper Silesian Anthropogenic Lake District is 185.4 km^2 (water bodies with an area of up to 1 ha occupy 10.32 km^2, while the total area of

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water bodies larger than 1 ha amounts to 175.04 km^2). Therefore lake density in the area amounts to 2.74% (of which 2.59% are water bodies with an area larger than 1 ha and 0.15% are water bodies with an area smaller than 1 ha). Locally, as evidenced by the results of measurements within grid cells, lake density exceeds ten per cent [1]. Around a dozen of the largest water bodies (Fig. 1) serve flood protection purposes and are sources of water for municipal, industrial, agricultural, transport, energy purposes, etc. Such usage of these water bodies is the main reason for fluctuations in their water levels, although obviously these also depend directly on their supply (rainfall, groundwater drainage, water transfers), and indirectly on the size of their catchment areas and the degree to which their basins are full. The most spectacular changes in water levels occur during high and (less frequent) low water stages.

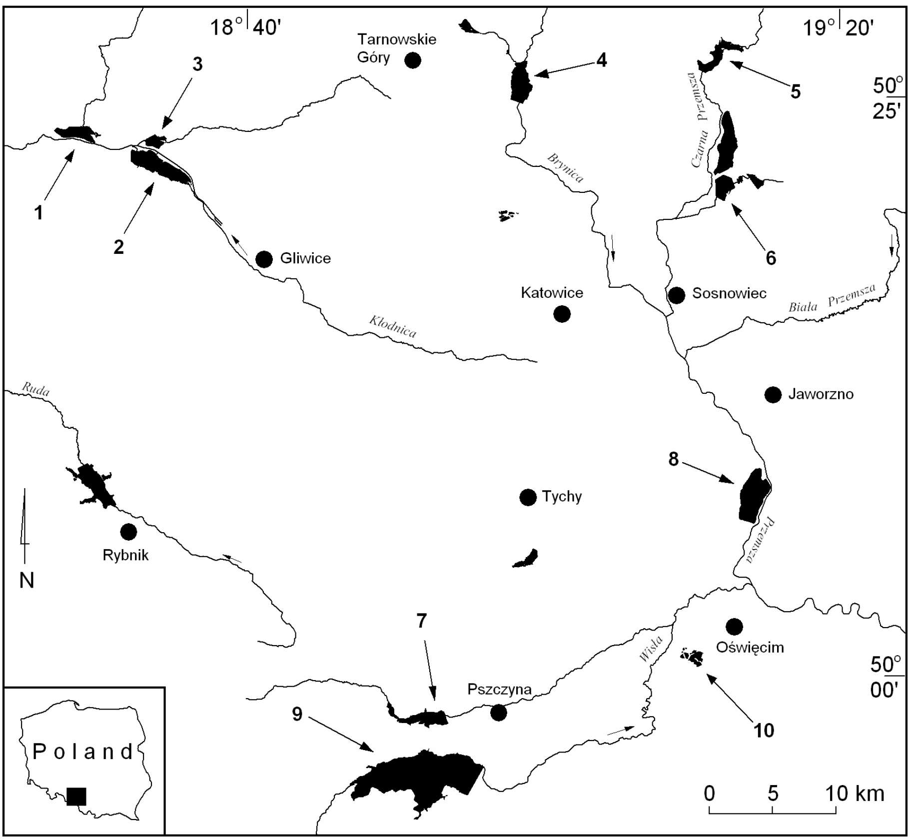

Fig. 1. Location of the man-made reservoirs included in the study: 1 - Plawniowice, 2 - Dzierzno Duze, 3 - Dzierzno Male, 4 - Kozlowa Gora, 5 - Przeczyce, 6 - Pogoria III, 7 - Laka, 8 - Dzieckowice, 9 - Goczalkowice, 10 - Harmeze

The objective of this study was to identify the scale of the change in water levels and water storages in artificial reservoirs in southern Poland during high and low water flows. Specific focus was placed on reservoirs in Upper Silesia (Fig. 1), a region standing out with

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a significant water resource deficit. Thus, the study offers a contribution to an on-going debate on the importance of artificial lakes for the water balance of this area.

Materials

The research involves the researchers' own investigations and observation data obtained from external sources, including the Regional Office for Water Management in Gliwice (RZGW), its predecessor the District Office for Water Management, the Katowice Water Utility (GPW), and the Institute of Meteorology and Water Management (IMGW) in Katowice.

The research consisted of the analysis of certain components of the water bodies' water balance. Primary data used included water stages recorded as a result of daily measurements of water levels in water bodies as well as in the rivers flowing through those water bodies. Water stage data were either logged automatically using limnigraphs or read from staff gauges. The knowledge of water stages and the parameters of hydrological cross-sections and basins made it possible to determine the quantity of water flowing into and out of the water bodies as well as the volumes retained in those water bodies. Administrators provided additional data on the volume of water sourced from the water bodies in question for municipal purposes and possibly supplied to those water bodies from outside the catchment area.

The figures obtained were used to identify the characteristics of the hydrological regime of those water bodies that are covered by water management. The analyses conducted concerned primarily water retention during high water stages and floods as well as during periods of insufficient rainfall because specific characteristics of the hydrological regime of anthropogenic lakes are most pronounced under extreme conditions.

Results and discussion

Retention in reservoirs gains importance during flood-flows and floods when catchments need to be protected, even if their stand-alone rather than cascade effect reduces their influence to mostly local or regional and only sometimes supra-regional [2]. The course of a flood-flow or a flood depends largely on the scale of the catchment's retention capacity in reservoirs. Flood prevention and management is normally the domain of large capacity lakes.

The importance of anthropogenic reservoirs in central southern Poland for water flow and flood management tends to be limited due to:

– Generally low water resources in a watershed zone separating the Vistula and Odra rivers.
– Existing alternatives in the management of much of the flood wave volume.
– High retention capacities of the catchments due their permeable formations and the existence of a depression sink.
– Limited flood reserve envisaged in the reservoir basins, except in the Goczalkowice lake.

Indeed, while any reservoir may offer a degree of flood prevention capability, an effective flood wave reduction potential is only associated with those lakes that are managed with a specific flood reserve capacity, which is often augmented by leaving much

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of their equalising capacity for use in the flood season. This includes the reservoirs of: Przeczyce at ca. 3 hm^3, Kozlowa Gora ca. 2 hm^3; Dzierzno Duze ca. 6 hm^3; Goczalkowice between 38 hm^3 in winter to 45 hm^3. Many reservoirs with either a minor or no ability to raise their water level have practically no flood prevention significance. They very much resemble natural lakes.

The assumptions adopted in the hydrotechnical studies on the water management of reservoirs during flood-flow and flood seasons mean that despite their low flood capacities, they still ensure a reduction of normal flood flows to harmless flow levels (*ie* permitted flows) and even a reduction of flows with the theoretical likelihood of 1% to flows that are lower than those recorded during the highest historical flood waves. In addition, only some of the reservoirs experience a very significant increase in water level and increase in retention at such times. In Upper Silesia these would be flood flows and rainfall-induced summer floods, both from torrential rainfalls and long-term rainfalls. Less frequently these would be from thaw-related flood-flows and floods, and only sporadically and strictly locally from wintertime flood-flows. Water-level changes recorded at such times on man-made reservoirs reflect the influence of individual reservoirs on river water levels. This influence depends on the capacity for increasing retention in reservoirs or on an increase in the discharge in a watercourse draining the waters (including an increased water abstraction for any purpose at that time), and often depends on both.

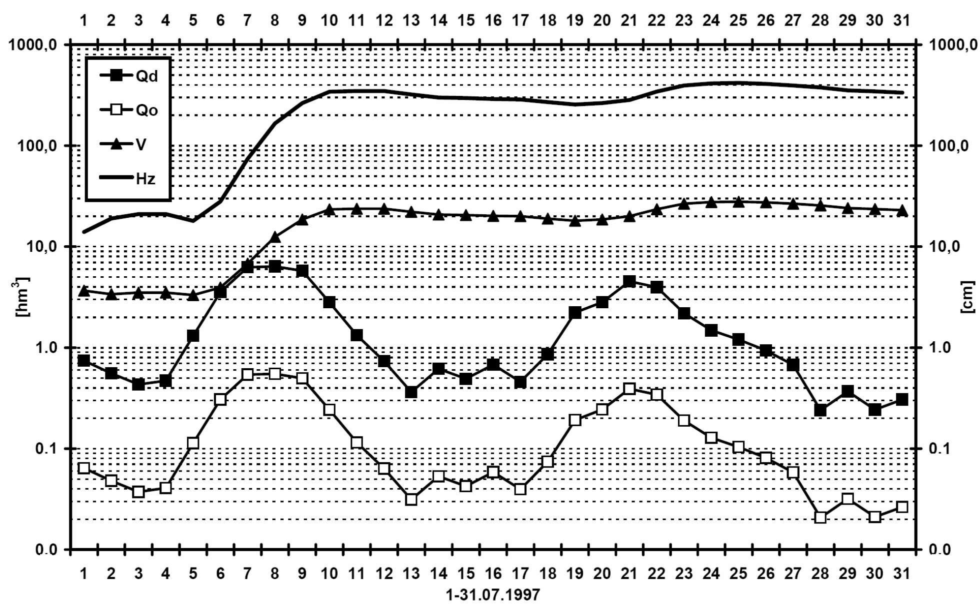

Fig. 2. Dzierzno Duze water reservoir - the selected hydrological characteristics of surface waters in the period of raised water stage due to rainfall in July of 1997 year (made by the authors on base of data taken from RZGW in Gliwice): Qd [hm^3] - size of 24 hours' input of water in the reservoir, Qo [hm^3] - size of 24 hours' water intake and spill from the reservoir, V [hm^3] - size of reservoir retention (V + 60 hm^3), Hz [cm] - height of water table in the reservoir (Hz + 198 m a.s.l.)

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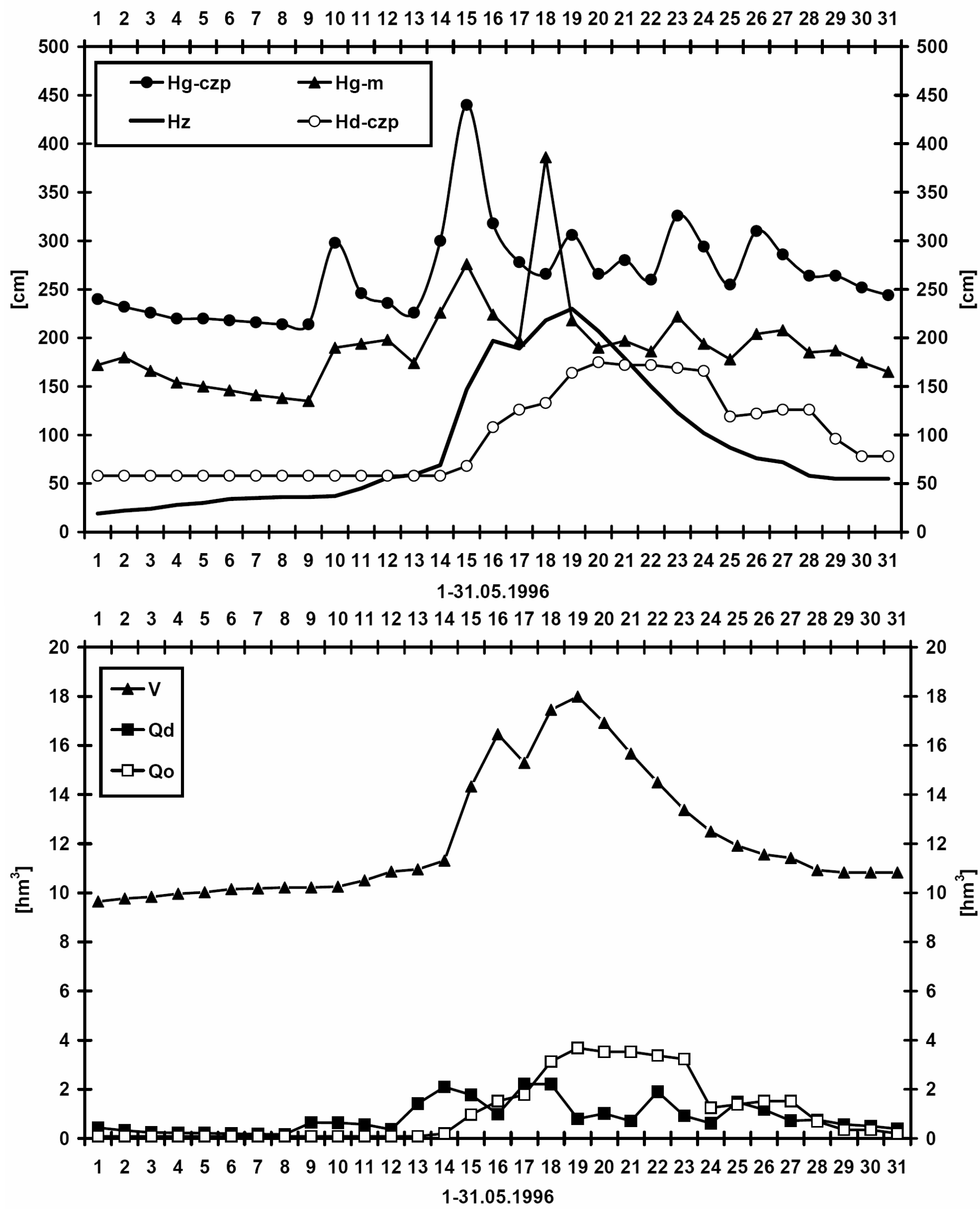

Fig. 3. Przeczyce water reservoir - selected hydrological characteristics of surface waters in May of 1996 year (made by the authors on base of data taken from RZGW in Gliwice): Hg-czp [cm] - water stages of the Czarna Przemsza in Siewierz (above the reservoir), Hg-m [cm] - water stages of the Mitrega in Kuznica Sulikowska (above the reservoir), Hd-czp [cm] - water stages of the Czarna Przemsza in Przeczyce (below the reservoir), Hz [cm] - height of water table in the reservoir (Hz + 287 m a.s.l.), V [hm^3] - size of reservoir retention, Qd [hm^3] - size of 24 hours' water input in the reservoir, Qo [hm^3] - size of 24 hours' water intake and spill from the reservoir

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In July 1997, spectacular flood-flows in the study area [3-5] doubled the water level in most of the region's reservoirs (Fig. 2). This was caused by extremely intensive rainfall across southern Poland and in the neighbouring Czech Republic. The rainfall event had three distinctive episodes: i) exceptionally intensive rains over a large area between 4 and 8 July; ii) 15 to 23 July peaking during 18-20 July; and iii) 24 to 28 July with a maximum between 24 and 28 July [3]. The highest daily inflows into the Upper Silesian reservoirs were observed on the days of peak flood-waves (8 and 21 July), followed by peak water levels in these reservoirs three to four hours later. The volume was managed according to a retention management plan and the reservoirs discharged just above one-third of the peak inflows, but some downstream areas still experienced small-scale flooding.

An event on the Przeczyce reservoir in May 1996 (Fig. 3) illustrates the operation of reservoirs at a time of catastrophic flood-flows caused by torrential downpours in the upper sections of the Odra and Vistula river systems. Barczyk and Szturc [3] find that the floods were caused by the runoff from intensive thunderstorm precipitation with very strong gusts of wind. Rainfall intensities in the Upper Przemsza river system peaked on 14 May (including at: Swierklaniec - 66.5 mm; Brynica - 74.5 mm; Pyrzowice - 81.4 mm; Piwon - 44.5 mm; Zawiercie - 70.8 mm) and on 17 May (Swierklaniec - 10.0 mm; Brynica - 6.3 mm; Pyrzowice - 41.0 mm; Piwon - 37.5 mm; Zawiercie - 56.8 mm) [3]. Within eight hours of the beginning of the rains and six hours from their peak intensity flood waves formed on the area's rivers. Water levels in reservoirs in northern Upper Silesia (Fig. 3) rose accordingly demonstrating their flood-risk mitigation function.

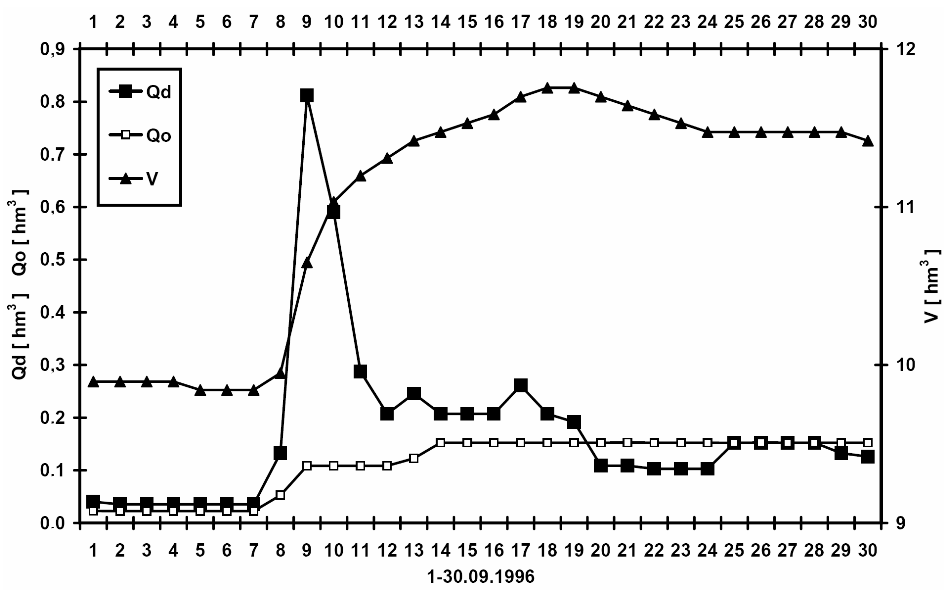

Fig. 4. Kozlowa Gora water reservoir - selected hydrological characteristics of surface waters in the period of raised water stage due to long-term rainfalls in September of 1996 year (made by the authors on base of data taken from GPW in Katowice): Qd [hm^3] - size of 24 hours' input of water in the reservoir, Qo [hm^3] - size of 24 hours' water intake and spill from the reservoir, V [hm^3] - size of reservoir retention

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There are numerous cases when flood-flows caused by intensive rains were equalised by reservoirs, *eg* in July 1970 and June 1998 (Dzierzno Duze), August 1977 and July 2000 (Kozlowa Gora and Dzierzno Duze). A model case of a reservoir's role in absorbing excess river flow after long-term precipitation is presented by an event in September 1996 when the Kozlowa Gora lake intercepted nearly 1 hm^3 of water from a flood wave within 24 hours of the rainfall, compared to the daily inflow of ca. 35000 m^3 before the event (Fig. 4). During a thaw-triggered flood-flow in March 1981, the Kozlowa Gora lake received ca. 1 hm^3 of water in one day. Similar effects were caused by thaw-induced flood-flows in February 1985 (Fig. 5) in Kozlowa Gora and in March 1996 in the Przeczyce lake (Fig. 6).

These examples of flood-flows in the Upper Silesian region provide evidence for the flood-control function of retention lakes at a local and regional scale. Indeed, in certain cases the discharge control on these reservoirs may have had an impact on flood-flow levels even in the upper parts of the Vistula or Odra river systems. It is worth noting that the flood-control function of the Upper Silesian reservoirs can be enhanced by numerous marshes not just in the river valleys, but also in mining subsidence zones on the valley sides and even in the watershed zones. These areas should be considered as periodic or ephemeral reservoirs or even flood polders in flood-control planning, alongside their retention roles. Indeed, a general demand for water and the need for effective flood-control measures have resulted in a high popularity of programmes that target both the importance of large existing and future reservoirs and what is known as small-scale retention capability for economic and living purposes over recent decades.

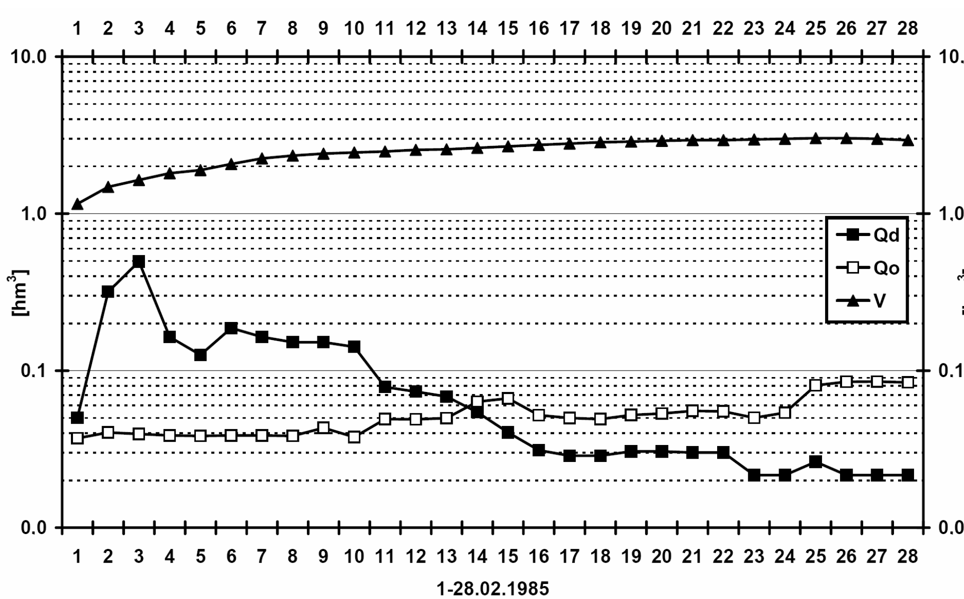

Fig. 5. Kozlowa Gora water reservoir - selected hydrological characteristics of surface waters in the period of raised water stage due to thaws in February of 1985 year (made by the authors on base of data taken from GPW in Katowice): Qd [hm^3] - size of 24 hours' input of water in the reservoir, Qo [hm^3] - size of 24 hours' water intake and spill from the reservoir, V [hm^3] - size of reservoir retention

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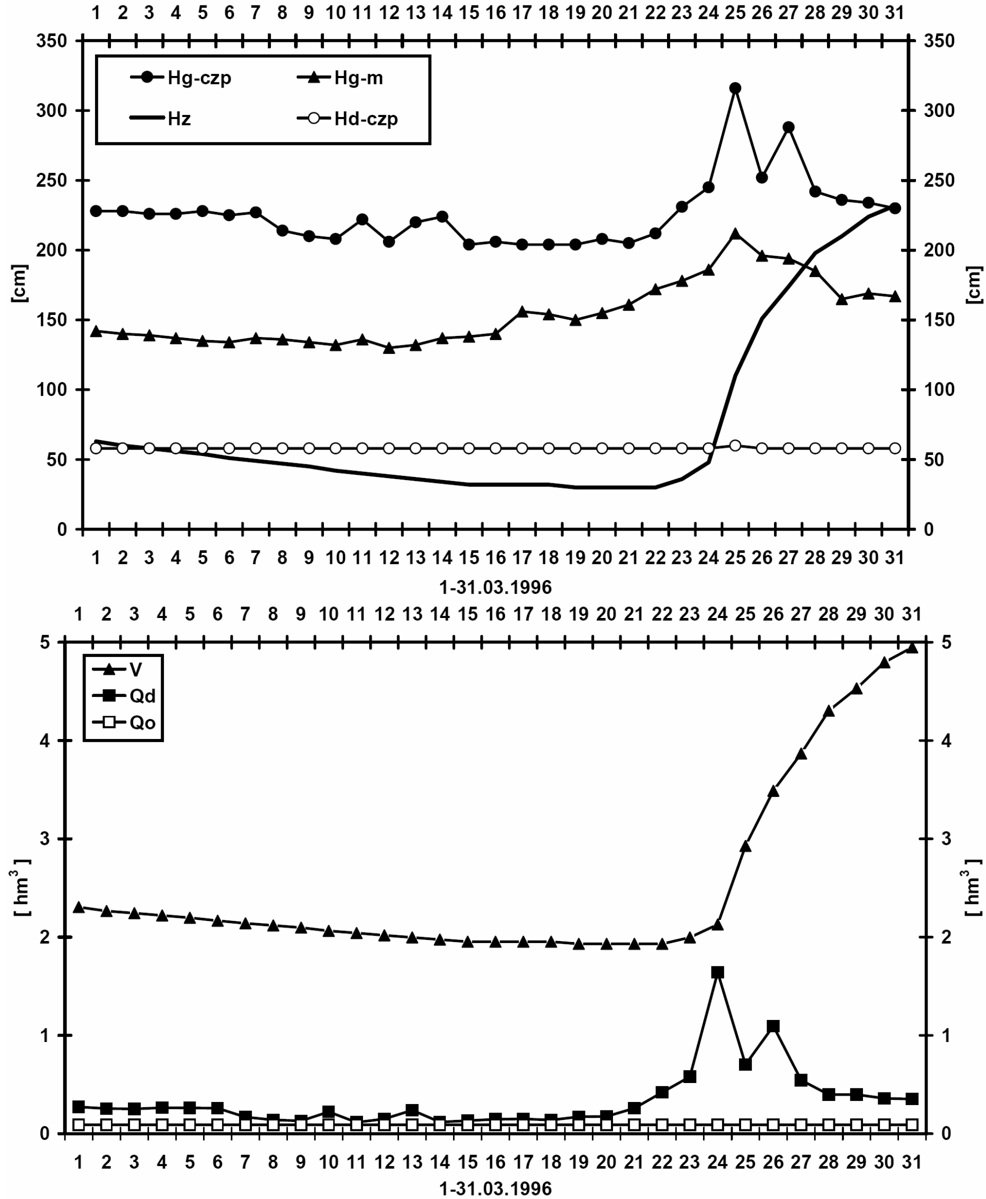

Fig. 6. Przeczyce water reservoir - the selected hydrological characteristics of surface waters in the period of raised water stage due to thaw in March of 1996 year (made by the authors on base of data taken from RZGW in Gliwice): Hg-czp [cm] - water stages in the Czarna Przemsza in Siewierz (above the reservoir), Hg-m [cm] - water stages of the Mitrega in Kuznica Sulikowska (above the reservoir), Hd-czp [cm] - water stages of the Czarna Przemsza in Przeczyce (above the reservoir), Hz [cm] - height of water table in the reservoir (Hz + 283 m a.s.l.), V [hm^3] - size of reservoir retention, Qd [hm^3] - size of 24 hours' water input in the reservoir, Qo [hm^3] - size of 24 hours' water intake and spill from the reservoir

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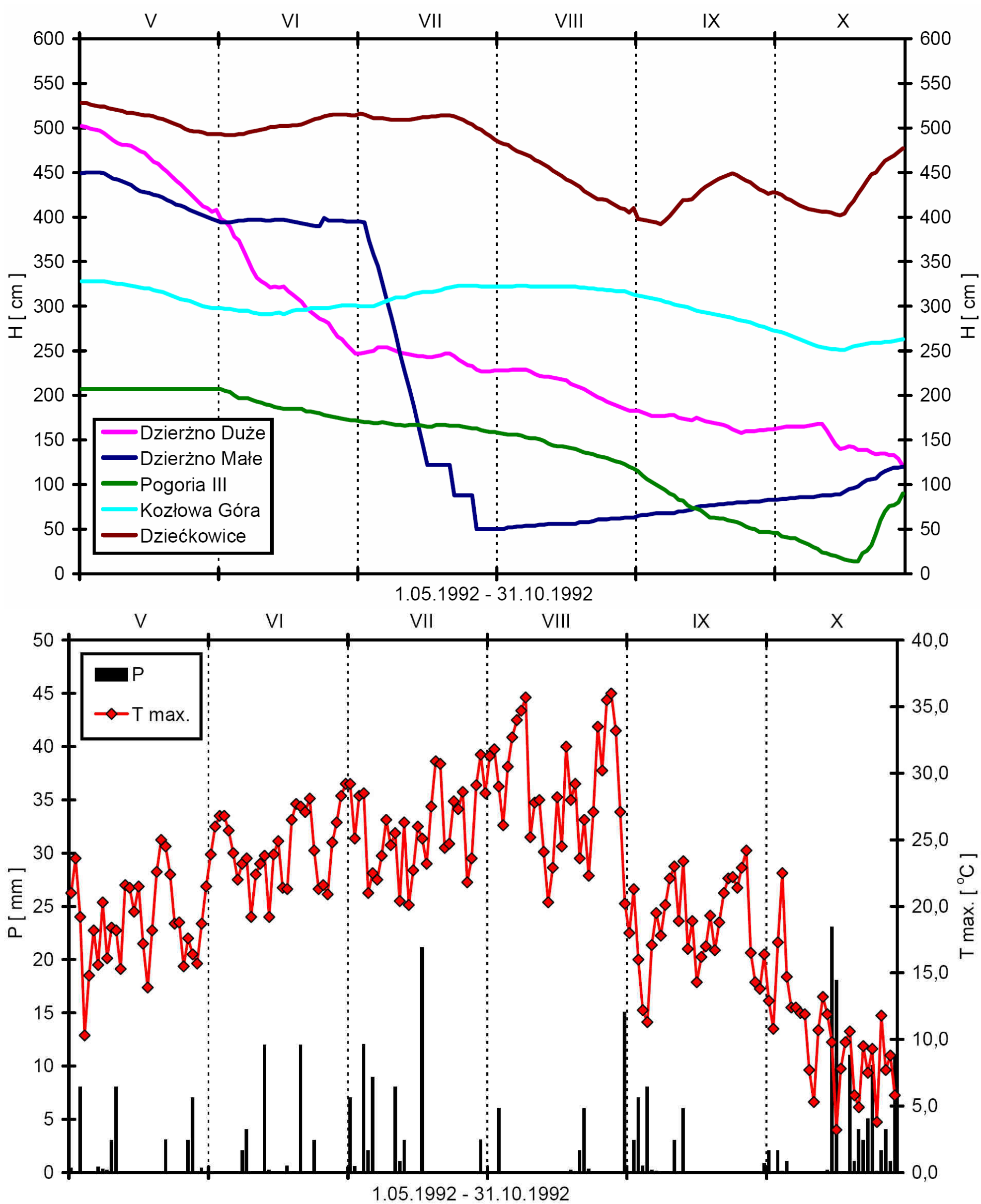

Fig. 7. Changes in height of water table in the selected water reservoirs against a background of variability of atmospheric precipitation and atmospheric air temperature during drought in 1992 year (made by the authors on the base of data taken from RZGW in Gliwice and IMGW and GPW in Katowice): H [cm] - course of 24 hours' water stages (Dzierzno Duze - 195 m a.s.l. + H; Dzierzno Male - 199 m a.s.l. + H; Pogoria III - 259 m a.s.l. + H; Kozlowa Gora - 274 m a.s.l. + H; Dzieckowice - 223 m a.s.l. + H); P [mm] - 24 hours' sums of atmospheric precipitation in Katowice [mm]; T max. [°C] - maximum 24 hours' temperatures in Katowice

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Water level fluctuations in reservoirs should not just be seen as a result of their flood-control activity, but also as a result of droughts. Dry spells can be as effective in causing water levels to drop towards minimum permitted levels, as is maintenance work on the reservoir infrastructure (Fig. 7). Droughts in southern Poland are somewhat less frequent than floods. During the period 1983-2012 they occurred in: 1983, 1992, 1994, 2003, 2011 and 2012. They were characterised by a slow and gradual lowering of the water levels in lakes, which was rapid only in isolated cases.

In lakes that are not subject to human pressure any water level changes are accounted for by weather conditions and climate change, which - when controlled for seasonality - may typically cause minor water level fluctuations ranging between single figures and tens of centimetres. Where there is human pressure, water levels also depend on the water management. Two types of reservoir can be identified in terms of their water level patterns: reservoirs with dominant natural drivers and ones subject to human impact (Fig. 8). The functioning of the former type in the landscape resembles that of lakes (*eg* Pogoria III and Plawniowice), while the latter offers a model example of the human influence on water level fluctuations (*eg* Dzierzno Duze, Laka and Dzierzno Male).

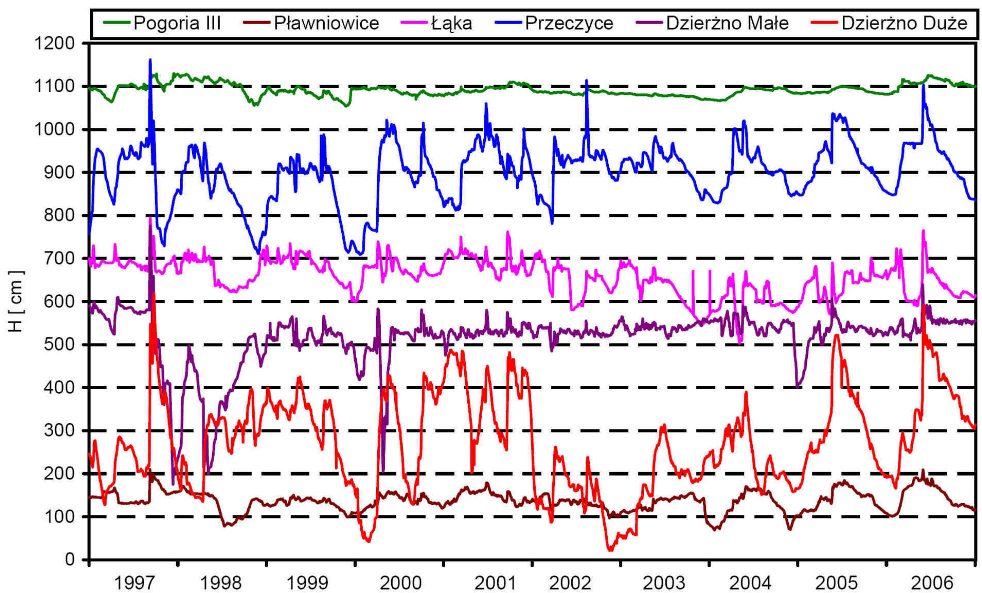

Fig. 8. Changes in daily heights of water table in reservoirs of different degree of anthropogenic load in the hydrological years 1997-2006 (made by the authors on the base data taken from RZGW in Gliwice): Pogoria III - 250 m a.s.l. + H; Plawniowice - 192 m a.s.l. + H; Laka - 243 m a.s.l. + H; Przeczyce - 278 m a.s.l. + H; Dzierzno Male - 198 m a.s.l. + H; Dzierzno Duze - 196 m a.s.l. + H

Water level fluctuations on stable reservoirs can sometimes reach values equivalent to the average depth of the reservoirs or even its maximum values, like in fishponds. In general, water level fluctuations in southern Poland are not something unusual, especially in dam-retained lakes [6], and correspond to analogous patterns in numerous typical retention

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reservoirs of the temperate zone, *eg* on the rivers Volga and Kama [7], the Angara river cascade [8, 9], both in Russia, or Lakes Zermanice and Terlicko in the Czech Republic.

A typical feature common in these reservoirs is that water level peaks are caused by flood-flows and their lowest values are caused by human demands [7, 9, 10]. Water level fluctuations in the largest reservoirs cause profound periodic changes in the functioning of their river valleys, which can be viewed as regional or supra-regional environmental, economic or even military issues, as reported by Zhao et al [11] and in a dissertation by Stamou et al [12], as well as in terms of natural beauty around smaller water bodies.

Conclusions

Periodical rises in water levels related to high water episodes caused by thawing or rainfall reach as much as several metres compared to the period preceding the high water episode. Drought periods result in the lowering of storage levels towards minimum ones as does similarly the intentional discharge of water from reservoirs. In water bodies in southern Poland, annual changes in water levels range from several centimetres to almost ten metres. The variability of levels is often similar to the average depth of the water body in question, in some cases approaching its maximum depth.

Artificial retention measures can cause certain economic damage, such as small-scale flooding of residential areas, agricultural and forest land and infrastructure, but also changes in geosystems resulting in shifts in habitat types from terrestrial or terrestrial-aquatic into typically aquatic types.

During wet or average years, a lowering of a lake's water level does not normally cause detrimental effects. In dry years, however, water deficits coincide with increased abstraction for economic purposes. As a consequence, the extreme decrease in lake water levels (cyclical in fish ponds and episodic in other reservoirs) is in stark contrast to the need to maintain minimum biological flows in surface watercourses. While extreme levels are regarded as marginal cases of a normal situation, high and low water flows must be regarded as detrimental from the nature conservation and socio-economic perspectives. How to assess the scale of damage caused by flood-flows within river valley bottoms is, however, a different matter affecting a single-digit percentage of the Polish territory, as is the assessment of droughts, which affect entire catchments.

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Abstrakt: Środkowa część południowej Polski to kraina jezior antropogennych. Na powierzchni 6766 km^2 (Górnośląskie Pojezierze Antropogenne) występują aż 4773 zbiorniki wodne, które łącznie zajmują 185,5 km^2. Kilkanaście największych zbiorników pełni funkcje przeciwpowodziowe i jest źródłem wody do celów komunalnych, przemysłowych, rolniczych, transportowych, energetycznych itp. Takie użytkowanie zbiorników jest główną przyczyną wahań zwierciadła wody, chociaż niewątpliwie zależą one także bezpośrednio od wielkości zasilania (opady, drenaż wód podziemnych, przerzuty wody), a pośrednio od powierzchni zlewni, stanu napełnienia misy. Najbardziej spektakularne zmiany poziomu wody występują w okresach wezbrań i rzadziej pojawiających się susz. Okresowe podpiętrzenia wody spowodowane wezbraniami roztopowymi lub opadowymi objawiają się podwyższeniem stanów wody nawet o kilka metrów w stosunku do okresu przedwezbraniowego. Okresy posuszne skutkują obniżeniem zwierciadła wody ku minimalnemu poziomowi piętrzenia, podobnie jak to ma miejsce w czasie celowych upustów wody ze zbiorników. W zbiornikach południowej Polski wahania stanów wody charakteryzują amplitudy roczne od kilku centymetrów do prawie 10 metrów. Często osiągają zakres bliski średniej głębokości akwenu, a w niektórych przypadkach odpowiadają zakresowi bliskiemu głębokości maksymalnej, co determinuje niespotykane w jeziorach naturalnych zmiany retencji wody.

Słowa kluczowe: pojezierze, region górnośląski, zbiorniki wodne, retencja, poziom wody

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