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# DIFFERENCES IN ICE COVER IN THE ANTHROPOGENIC RESERVOIR OF PŁAWNIOWICE IN THE YEARS 1986–2012

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**Keywords:** Ice phenomena, anthropogenic reservoirs, Pławniowice lake.

**Abstract:** The article presents changes in the thickness and duration of the ice cover found in the restored anthropogenic water reservoir of Pławniowice. It also defines the role the ice cover plays in the formation of the reservoir limnological cycle. Characteristic and significant changeability of the ice cover thickness and duration was observed. The changes in the ice cover demonstrate that they are cyclical but not regular. The ice cover did not always form in the analyzed period. It happened twice, i.e. in 1988 and 2007 (a gap of 20 years). The longest lake freezing period lasted 119 days. Changes in the ice cover duration also show certain periodicity. The shortest periods occurred approx. every 7 years. Maximum values of the ice cover thickness ranged between 10 and 52 cm. There is a relation between the ice cover thickness and its duration period. The rate of increase in the ice cover thickness varied between 0.296 and 3.6 cm/d. The hypolimnion removal impact on the ice cover duration period and thickness was not observed. On the other hand, the ice cover duration period affects the spring circulation duration. Thus, it has an influence on the oxygen balance of the limnic ecosystem.

## INTRODUCTION

Ice phenomena in water reservoirs (lakes, anthropogenic reservoirs) understood as the occurrence of ice in its various forms are complex [2, 12, 22]. They include both precipitation in winter and its role in the ice formation as well as the establishment of a permanent ice cover [1, 2, 11].

Ruman and Rzętała [20] emphasize that the subject of ice phenomena is not often discussed in the Polish limnological literature. The first Polish researcher who handled this matter was Matusewicz in 1939 [16]. He was followed by Lityńska [12] in 1965, Grześ [6] in 1974 and Gołek [5]. Early Olszewski's, Patalas's and Pasławski's works also discussed the importance of ice phenomena [18–20]. Studies by Gierszewski [4], Jankowski [7], Machowski [14] as well as Ruman, Rzętała, Skowron, Solarski and Strugała [21–27] provide scholars with knowledge of ice phenomena in anthropogenic water reservoirs.

The majority of Polish stratifying lakes and reservoirs are dimictic due to the characteristics of the Polish climate [1, 13, 18]. Their water masses are mixed under the wind influence and under homeothermic conditions occurring in fall as well as in spring, after the ice cover disappears [1, 11, 17, 20].

The oxygen balance of the reservoir and, hence, the capacity of the reservoir for the aerobic decomposition of the organic matter produced in the reservoir or introduced with the inflow water depend on the time during which water masses become aerated and water temperature, which determines the solubility of the oxygen in water [8, 13, 17, 18]. For that reason, the spatial variability of the ice cover [14, 16, 24–26] and its duration period [16, 21–23] are carefully observed. The research usually embraces one or two winter seasons [7, 25, 26]. Long-term and systematic measurements recommended by Gołek [4] are very sporadic [20].

The dependence between thickness of the ice cover and thermal air and water conditions on the North Poland lakes was investigated [4, 17, 26, 27]. In this work the seasons and long term changes of ice cover are presented.

## MATERIAL AND METHODS

As it separates water masses from the oxygen admission, the ice cover begins the winter stagnation in the reservoir. The aim of the following research was to describe the dynamics of the ice cover formation in Pławniowice reservoir in the years 1986–2012. Another objective was to define the role of the ice cover in the limnological cycle, specifically its influence on the duration of fall and spring circulations. Pławniowice reservoir has been restored with the hypolimnion removal method (the Olszewski's tube) since December 2003 [8–10]. Due to that fact, the measurement data concerning the duration of specific limnological cycle periods was analyzed. Consequently, the impact of the ice cover occurrence on the duration of circulation and stagnation periods was defined.

The investigated anthropogenic reservoir of Pławniowice (Silesian Voivodship) was established in 1974 by means of flooding an exploited stowing sand borrow pit. Its area is 225 ha and its volume is 29 million $m^3$ [8–10]. As the Regional Office for Water Management in Gliwice manages and controls the reservoir, it performs routine measurements of the ice cover thickness and duration.

The thickness measurements were carried out by means of drilling the ice cover with a drill (20-mm diameter). They were begun once the ice cover appeared. And continued on a daily basis until the ice cover disappeared. The initial measurements were taken on the pier near the lakeside as the ice cover was rather thin. Once the ice cover reached the thickness of 10 cm, which enabled the researcher to enter the frozen lake surface, the measurements were performed as far as 100 m from the lakeside.

## RESULTS

The study presents the analysis and scientific measurement data concerning the ice cover duration and thickness as well as the interdependence of both these elements. Long-term measurements indicate large differences in the formation of the ice cover in Pławniowice reservoir (Fig. 1). The subsequent years differ not only in the number of days when the reservoir was completely covered with ice but also in the ice cover thickness. The similarity of the subsequent yearly winter periods in those terms was very seldom.

Analyzing the Pławniowice measurement results in the years 1986–2012 (Fig. 1) allows for differentiating 4 groups that vary in their maximum ice cover thickness. The first one covers 2 years (1988 and 2007), when the ice cover did not form at all. The second one embraces 6 years (1989, 1990, 1992, 1995, 2001 and 2008), when it did not exceed the thickness of 20 cm. 7 years (1994, 1998, 2000, 2002, 2004, 2005 and 2009) constitute the third group. In those periods the ice cover thickness ranged between above 20 and 30 cm. Finally, the last one includes 12 years (1986, 1987, 1991, 1993, 1996, 1997, 1999, 2003, 2006, 2010, 2011 and 2012), when the thickness varied between above 30 and 52 cm.

Apart from the 2 years when the reservoir was not frozen at all, the thinnest ice cover thickness, which amounted to max. 10 cm, was observed in 1989, 1990, 1992, 2001 and 2008. The ice cover appeared twice in 1989, 1992, 1993, 2001, 2004 and 2012. The ice disappeared between those two phases of freezing-up.

As can be seen (Fig. 1), the ice cover thickness increase is not linear. It is particularly visible in certain years, i.e. 1993, 1999, 2004, 2005 and 2011. The ice becomes thinner after the periods in which its thickness rises. Then, the cover increases again. The changes were the least dynamic and both the increase and disappearance of the ice cover were the steadiest in the years when the ice cover was the thickest (1986, 1987, 1991, 1996, 2006, 2010 and 2012). The greatest dynamics of the ice thickness changeability was observed in 1993, 1999, 2003, 2005 and 2011.

Comparing maximum values of the ice cover thickness in subsequent years points to large changeability (Fig. 2). The discussed value ranged between 0 (as the reservoir did not freeze in 1988 and 2007) and 52 cm. The thickest ice cover was observed in 1987 (49 cm), 1991 (52 cm) and 1996 (50 cm).

Changes in the ice cover thickness demonstrate their cyclic but irregular character (Fig. 2). The ice thickness notably decreased in the years 1986–1988. The largest discrepancy occurred between 1987 and 1988. The ice cover thickness gradually rose in the years 1988–1996. It diminished again between 1996 (maximum ice thickness – 50 cm) and 2007 (lack of the ice cover). An upward trend was observed between 2007 (no ice cover) and the winter season of 2011–2012 (maximum ice thickness – 36 to 38 cm). As it is visible, the gap between periods without the ice cover amounted to 20 years. What is more, the ice cover reached its largest thickness in the middle of that period.

The biggest similarity in terms of the ice thickness in subsequent years was noted in the years 2002–2006 (22 to 28 cm) and 2010–2012 (36 to 38 cm).

The duration of the ice cover during the research varied between 0 days in 1988 and 2007 (lack of ice) and 119 days in 1996 (Fig. 3).

Differences in the ice cover duration also reveal certain periodicity. The diagram (Fig. 3) shows the following periods: 1988–1995, 1995–2001, 2001–2007 and 2007–2012. The lowest values appear every seven years. The most visible increase in the number of days when the reservoir was completely covered with ice is seen between 1988 and 1993 and then between 2007 and 2011.

The maximum thickness of the ice is related to the cover duration (Fig. 4).

The rate of increase of the ice cover in Pławniowice reservoir was defined with both these parameters (Fig. 5). Its value extended between 0.29 and 3.6 cm/d for the investigated period and with the exclusion of 1988 and 2007, i.e. the years when the ice cover did not form.

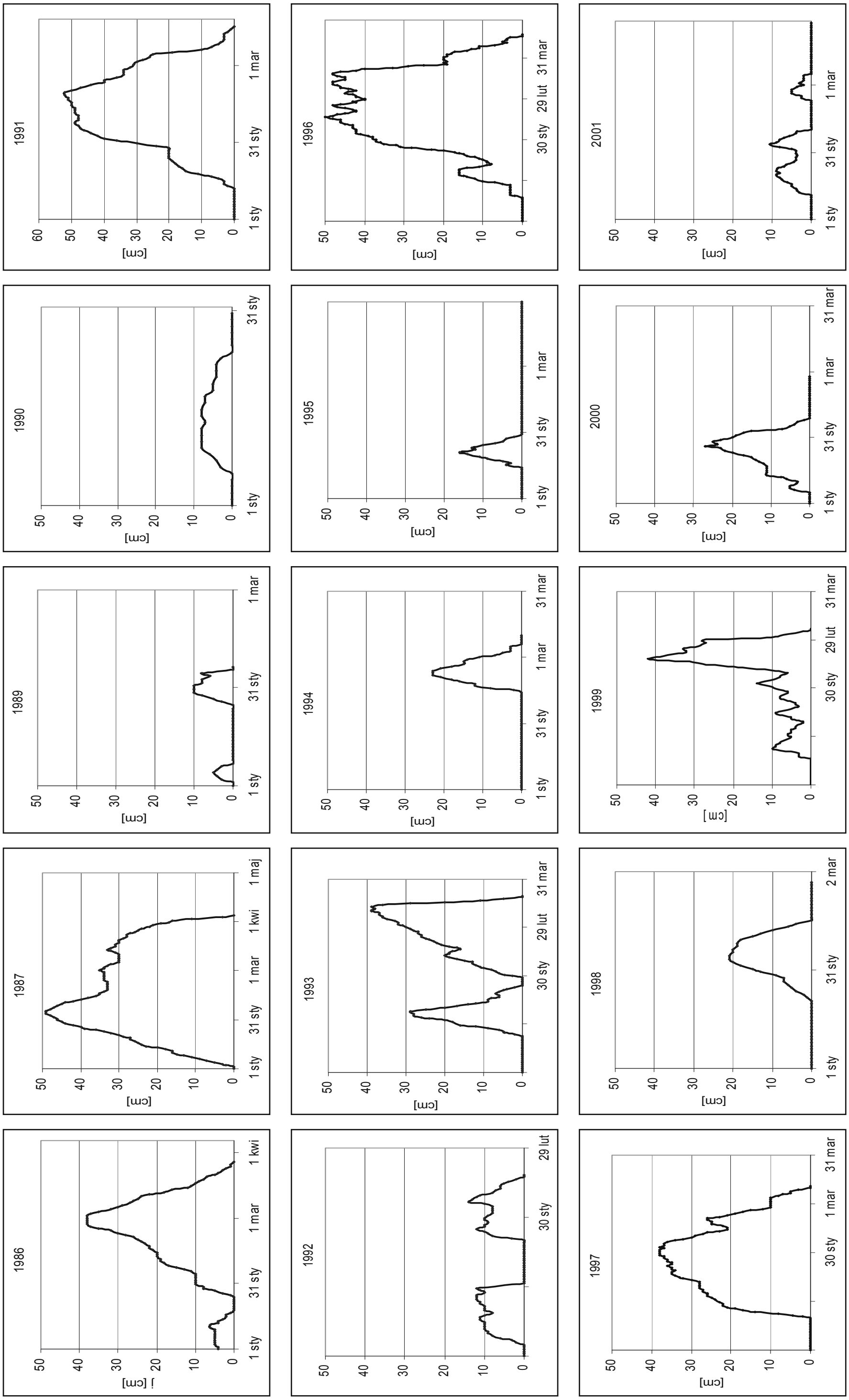


Fig. 1. Ice cover duration and thickness – Pławniowice reservoir, 1986–2012

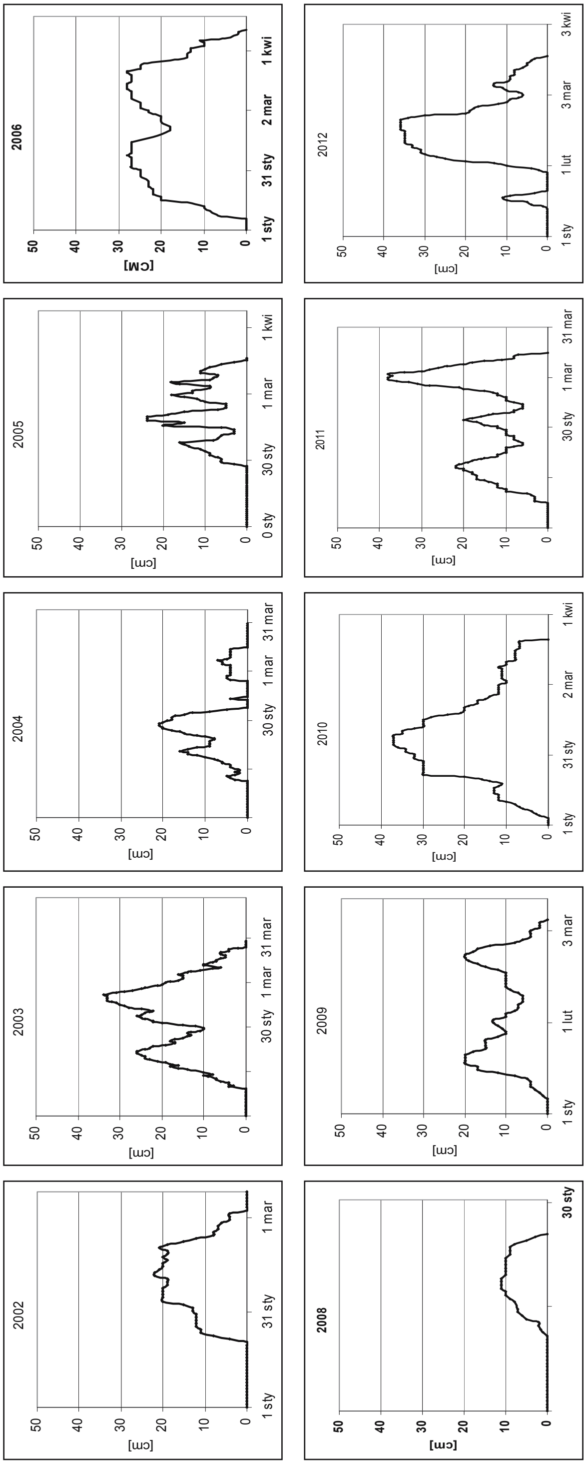


Fig. 1. Ice cover duration and thickness – Pławniowice reservoir, 1986–2012

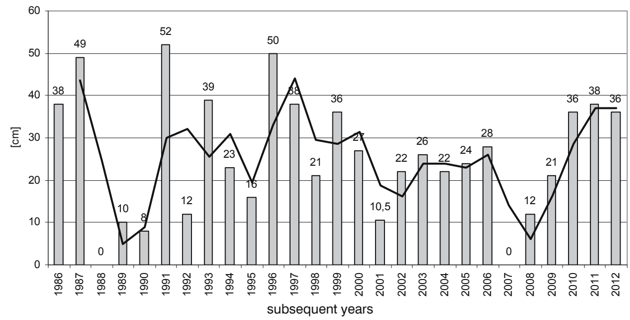


Fig. 2. Maximum ice cover thickness in Pławniowice reservoir, 1986–2012

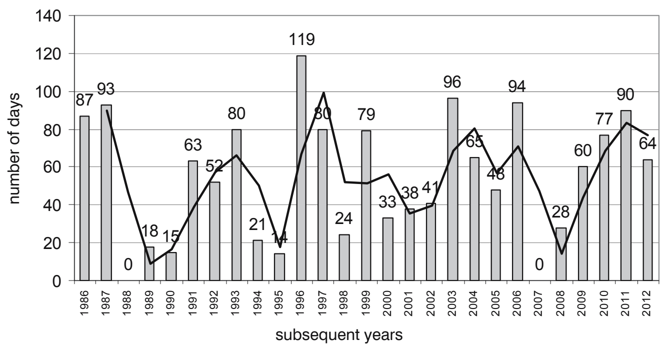


Fig. 3. Number of days with ice cover – Pławniowice reservoir, 1986–2012

Air temperature and the increase in the ice cover thickness are closely related [1, 5, 10, 14]. The visible abrupt changes in the increase of the ice cover (Fig. 5) in Pławniowice reservoir indicate that the air temperature changes in a highly dynamic way in winter periods.

The morphometric conditions also affect the spatial variability of the ice cover thickness. They embrace factors such as the depth (including the average depth), reservoir capacity and area, topographic features of the surrounding area and barriers such as hills, forests or buildings [1, 2, 6, 20, 22]. The results of the ice thickness measurements performed during one or two winter periods to demonstrate its spatial variability [4, 13, 23, 24] point to specific factors characteristic for a given reservoir. The ice cover thickness rises as a consequence of the fact that deeper and deeper water layers freeze and layers of the freezing snow build up [2, 14]. Having a large number of measurements enables the researcher to analyze them in a more detailed way in terms of the increase and decrease of the ice cover thickness.

As it has already been mentioned, the ice thickness in Pławniowice reservoir was measured at one measurement position. It covered an area of approx. 400 m$^2$. What can be seen in the diagrams (Fig. 1) are the observed subsequent series of measurements, which are characterized by abrupt changeability. The data coming from 1992, 1996, 1999 and 2005 is especially interesting. Winters in 1992, 1999 and 2005 were rather mild.

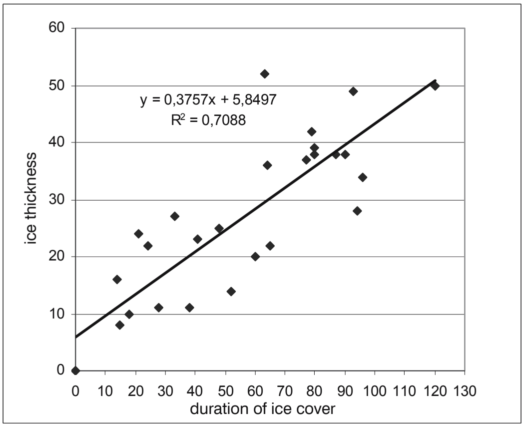


Fig. 4. Relation between the thickness and duration of the ice cover – Pławniowice reservoir, 1986–2012

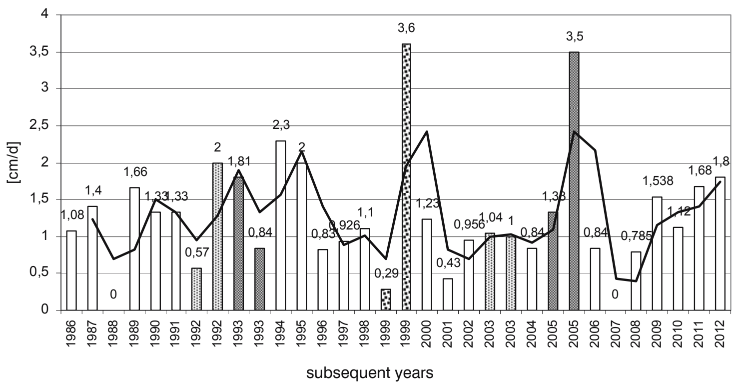


Fig. 5. Rate of increase in the ice cover – Pławniowice reservoir, 1986–2012

The differences in results ranged between 8 and 14 cm in 1992, 4 and 10 cm in 1999 and 8 and 18 cm in 2005. Winter in 1996 was long and severe [20]. As a result, the ice cover of Pławniowice reservoir reached the thickness of 52 cm (Fig. 1).

It seems important that the discrepancy in the measurements carried out during the thickest ice cover period amounted to 10 cm (40 and 50 cm). It appears that the ice cover thickness is not only dependent on winter season duration (Fig. 4). The ice cover thickness may vary between 4 and 10 cm in a relatively small area and at a close distance. Ruman refers to that fact [22] and demonstrates that the ice cover thickness depends on the circulation and thermal conditions of the water mass.

The duration of particular stages of the limnological cycle (Table 1) was defined for those years for which the temperature measurement results were available [9–10].

As mentioned before, the oxygen solubility depends on water temperature. The oxygen load introduced into water is governed by the number of days when water masses are mixed under the wind influence [9, 17, 18]. The analysis of the interdependences between the duration of winter stagnation and spring circulation indicates that the ice cover duration determines the duration of spring mixing (Fig. 6).

## CONCLUSIONS

The glaciation process is determined by atmospheric conditions, morphology and morphometrics of the reservoir as well as the water supply method [1, 2, 12, 16]. The researchers who investigate ice phenomena emphasize their high complexity. They agree that the ice cover changes both in time and space [2–5, 21, 22–26]. The range of the ice

Table 1. Number of days in particular stages of the limnological cycle – Pławniowice reservoir, 1993–2011

| Years | Winter stagnation | Spring circulation | Summer stagnation | Fall circulation |
|---|---|---|---|---|
| | Number of days | | | |
| 1993 | 85 | 53 | 131 | 147 |
| 1995 | 14 | 96 | 168 | 61 |
| 1996 | 120 | 19 | 176 | 54 |
| 1997 | 80 | 77 | 140 | 70 |
| | | | | |
| 2004 | 65 | 42 | 152 | 116 |
| 2005 | 48 | 82 | 119 | 96 |
| 2006 | 93 | 28 | 147 | 90 |
| 2007 | 0 | 103 | 139 | 54 |
| 2008 | 28 | 105 | 155 | 91 |
| 2009 | 60 | 46 | 145 | 82 |
| 2010 | 76 | 45 | 133 | 91 |
| 2011 | 90 | 51 | 154 | 100 |

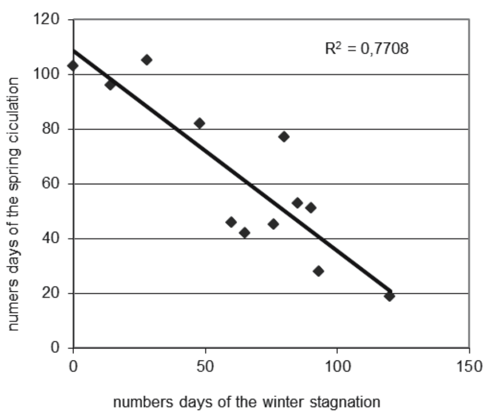


Fig. 6. Relation between the number of days of winter stagnation and spring circulation periods – Pławniowice reservoir, 1993–2011

cover spatial variability in anthropogenic reservoirs of the Katowice Uplands (Wyżyna Katowicka) is defined as 5 cm [13], 6–8 cm [2, 6], 11 cm [2] and 4–9 cm [2].

The ice cover duration in Pławniowice reservoir ranged between 0 and 119 days per year in the investigated period. The changes concerning this factor demonstrate certain periodicity. The lowest values appear every 7 years.

Analyzing the measurements of the ice cover thickness in Pławniowice reservoir displays its wide variability. The ice cover thickness ranged between 0 (no ice cover) and 52 cm during the studied period.

The course of the changes in maximum values of the ice cover thickness shows that their character is cyclical. It was observed in the scrutinized period that the gap between seasons when there was no ice cover was 20 years. The ice cover reached its maximum thickness in the middle of this period.

Long-term research and observations [8–10] demonstrate that even though the impact of the ice cover movement on the lakeside changes is described in the literature, it does not occur in Pławniowice reservoir.

The maximum ice thickness depends on the cover duration. The rate of increase in the thickness of the Pławniowice ice cover ranged between 0.296 and 3.6 cm/d in the analyzed period.

Comparing the Pławniowice (author's own data) measurement data with that of Turawa and Kozłowa Góra reservoirs (data of Ruman, Rzętała) [22] helped to establish independences between those three establishments in terms of the ice cover duration (Fig. 7 and 8).

The interdependences visible in Figs 7 and 8 demonstrate similar tendencies that characterize the development of the ice cover duration in various Silesian anthropogenic reservoirs [20]. On the other hand, the differences in the ice cover thickness manifest the diversification of the local climate conditions, even though the reservoirs are placed relatively close to one another [5, 7, 21, 22]. The relation between the ice cover thickness and the average depth of Pławniowice, Turawa and Kozłowa Góra reservoirs [Ruman, Rzętała 22] indicates that the ice cover is thicker in the reservoirs whose average depth is larger than in those in which it is shallower (Fig. 9).

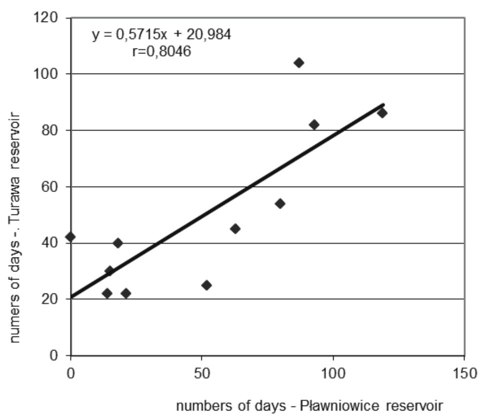


Fig. 7. Interdependence between Turawa and Pławniowice ice cover duration periods, 1986–1996

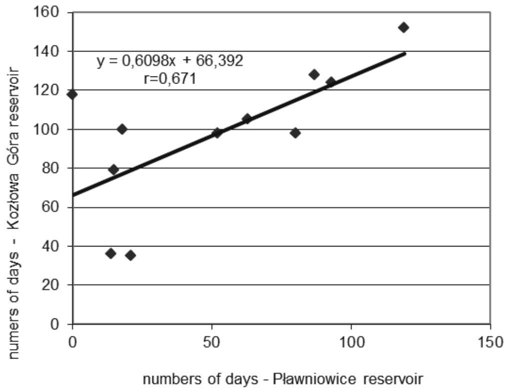


Fig. 8. Interdependence between Kozłowa Góra and Pławniowice ice cover duration periods, 1986–1996

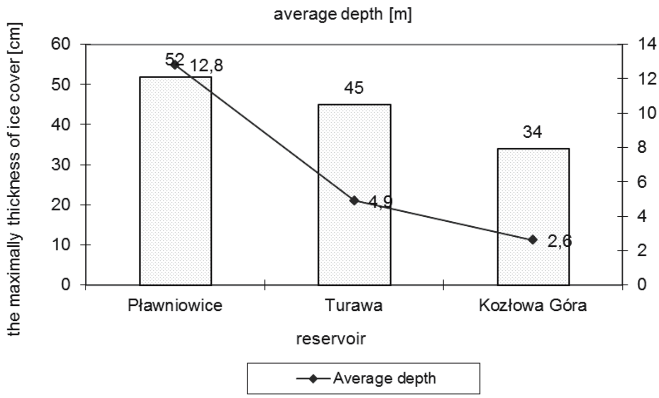


Fig. 9. Interdependence between the maximum ice cover thickness and average depth of the reservoirs

Analyzing measurement data (1986–2012) shows that the ice cover duration determines the length of the spring circulation period. Consequently, it turns out that ice phenomena, specifically the duration of a dense ice cover, play an important role in the oxygen balance of the anthropogenic reservoir. Systematic and long-term measurements of the physical and chemical factors constitute the basis and crucial condition when it comes to determine trends and regularities as well as prognoses concerning the development of ice phenomena in limnic ecosystems.

## REFERENCES

[1] Choiński, A. (1995). Zarys limnologii fizycznej Polski. Wydawnictwo Naukowe UAM, Poznań, 298, 1995.

[2] Choiński, A., Gałka, M., & Ławniczak, A. (2006). Przykłady zróżnicowania grubości pokryw lodowych wybranych jezior, Badania fizjograficzne nad Polską zachodnią, *Seria A – Geografia Fizyczna*, 57, 15–20.

[3] Dąbrowski, M., Marszelewski, & W. Skowron, R. (2004). The trends and dependencies between air and water temperatures in the lakes located in Nothern Poland in the years 1961–2000, *Hydrology and Earth System Sciences*, 8, 1, 79–87.

[4] Gierszewski, P. (1998). Zmiany brzegów wywołane termicznymi ruchami lodu na przykładzie zbiornika Włocławskiego, *Przegląd Geograficzny*, 66/4, 657–674.
[5] Gołek, J. (1986). Zjawiska lodowe w wodach powierzchniowych, (in:) Atlas hydrologiczny Polski, Warszawa 1986.
[6] Grześ, M. (1974). Badania nad termiką i zlodzeniem jeziora Gopło. PAN, Inst. Geogr. Dokumentacja Geogr., 3, Warszawa 1974.
[7] Jankowski, A.T., Machowski, R., Piątek, M., Rzętała, M., Rzętała, M.A., & Solarski, M. (2009). Cechy charakterystyczne zlodzenia zbiorników wodnych w regionie górnośląskim (In:) Marszelewski, W. (Ed.): Anthropogenic and natural transformations of lakes, 3, 103–108, 2009.
[8] Kostecki, M. (1977). Chemizm wód oraz podstawowe wskaźniki określające intensywność krążenia materii w zbiorniku zaporowym, w Pławniowicach, *Archiwum Ochrony Środowiska*, 3–4, 163–182.
[9] Kostecki, M. (2006). Hypolimnetic withdrawal as a restoration technique of Pławniowice anthropogenic reservoir, The International Conference on prof. dr hab. Marek Kraska's 70-year jubilee and the 15-th anniversary of the Department of Water Protection Feculty of Biology; Adam Mickiewicz Uniwersity, "The Functioning of Water Ecosystems and their Protection, 2006.
[10] Kostecki, M. (2007). Rekultywacja zbiornika Pławniowice metoda kortowską, VI Konferencja Naukowo--Techniczna „Ochrona i rekultywacja jezior", Toruń, 99–115, 2007.
[11] Lange, W. (ed.) (1993). Metody badań fizycznolimnologicznych, Wyd. UG Gdańsk, 175, 1993.
[12] Lityńska, Z. (1965). Prognoza zamarzania Jeziora Mikołajskiego, *Prace PIHM*, 96, Warszawa, 1965.
[13] Lossow, K. (1980). Wpływ sztucznej destratyfikacji na układy fizyczno-chemiczne wód jez. Starodworskiego. *Zesz. Nauk. Art.,* 11, 3–66.
[14] Machowski, R. (2009). Przebieg zjawisk lodowych zbiornika Czechowice (in:) Jankowski, A.T., Absalon, D., Machowski, R., & Ruman, M. (eds.). Przeobrażenia stosunków wodnych w warunkach zmieniającego się środowiska, Sosnowiec, 187–196, 2009.
[15] Marszelewski, W., & Skowron, R. (2009). Extreme ice phenomena on the lakes of Nothern Poland, *Limnological Review*, 9, 2–3, 81–89.
[16] Matusewicz, J. (1939). Badania nad zlodzeniem jezior w Polsce, *Wiadomości Służby Hydrologicznej i Meteorologicznej,* 2, 1.
[17] Mientki, Cz., & Dunalska, J. (1997). Wpływ mieszania wiosennego na wybrane parametry fizykochemiczne wody Jeziora Kortowskiego w okresie stagnacji letniej. (Impact of the spring turnover on the selected physic-chemical water parameters of Lake Kortowskie during the summer stagnation), XVII Zjazd PTH, Poznań 1997.
[18] Olszewski, P. (1959). Stopnie nasilenia wpływu wiatru na jeziora. *Zesz. Nauk WSR*, 4.
[19] Pasławski, Z. (1982). Zlodzenie jezior w Polsce, *Przegląd Geograficzny* 27, 1–2, 97–92.
[20] Patalas, K. (1960). Mieszanie wody jako czynnik określający intensywność krążenia materii w różnych morfologicznie jeziorach okolic Węgorzewa, *Roczniki Nauk Rolniczych,* 77, 1.
[21] Piątek, M., Solarski, M., Rzętała, M., & Pardela, A. (2010). Przebieg zjawisk lodowych w wybranych antropogenicznych zbiornikach wodnych Wyżyny Katowickiej, (Ice phenomena in chosen anthropogenic water reservoirs of Katowice Upland), (In:) Ciupa, T., & Suligowski, R. (Eds.). Woda w badaniach geograficznych, Kielce, 243–252, 2010.
[22] Ruman, M., & Rzętała, M. (2005). Zróżnicowanie pokrywy lodowej zbiorników zaporowych Turawa i Kozłowa Góra w latach hydrologicznych 1975–1996. (In:) Jankowski, A.T., & Rzętała, M. (Eds.), Jeziora i sztuczne zbiorniki wodne – procesy przyrodnicze oraz znaczenie społeczno-gospodarcze, Sosnowiec, 189–196, 2005.
[23] Rzętała, M. (2003). Procesy brzegowe i osady denne wybranych zbiorników wodnych w warunkach zróżnicowanej antropopresji (na przykładzie Wyżyny Śląskiej i jej obrzeży), Katowice, 147, 2003.
[24] Skowron, R., & Szczepanik, W. (1988). Zróżnicowanie przestrzenne i tendencje zmian przebiegu zjawisk lodowych w jeziorach Polski Północnej. (In:) Naturalne i antropogeniczne przemiany jezior i mokradeł w Polsce, Toruń, 1988.
[25] Skowron, R. (2011). Zróżnicowanie i zmienność wybranych elementów reżimu termicznego w jeziorach na Niżu Polskim (The differentiation and the changeability of chosen of elements the thermal regima of waters in lakes on Polish Lowland), Rozprawy Monograficzne, Wyd. Uniwersytetu Mikołaja Kopernika, Toruń, 1–245, 2011.
[26] Solarski, M., & Pardela, A. (2010). Przebieg zjawisk lodowych w zbiorniku wodnym w niecce osiadania w sezonie zimowym 2008/2009, Kształtowanie środowiska geograficznego i ochrona przyrody na obszarach uprzemysłowionych i z urbanizowanych, 42, 70–79.

[27] Strugała, B. (2006). Zróżnicowanie pokrywy lodowej wybranych zbiorników wodnych w Świętochłowicach w 2006 roku. (In:) Machowski, R., & Ruman, M., (Eds.), Z badań nad wpływem antropopresji na środowisko, Sosnowiec, 7, 98–101.

## ZRÓŻNICOWANIE POKRYWY LODOWEJ W ZBIORNIKU ANTROPOGENICZNYM PŁAWNIOWICE, W WIELOLECIU 1986–2012

W artykule przedstawiono zmiany okresu występowania oraz grubości pokrywy lodowej rekultywowanego antropogenicznego zbiornika wodnego w Pławniowicach. Określono rolę pokrywy lodowej w kształtowaniu cyklu limnologicznego zbiornika. Stwierdzono charakterystyczną, znaczną zmienność długości okresu występowania oraz grubości pokrywy lodowej. Zmiany grubości pokrywy lodowej wskazują na ich cykliczny, choć nie regularny charakter W analizowanym okresie dwukrotnie, w odstępie 20 lat (1988, 2007) stwierdzono brak pokrywy lodowej. Najdłuższy okres zlodzenia wynosił 119 dni. Zmiany długości okresu występowania pokrywy lodowej również wykazują pewną cykliczność. W tym przypadku najkrótsze okresy występowały, co około 7 lat. Maksymalne wartości miąższości pokrywy lodowej w poszczególnych latach wynosiły od 10 cm do 52 cm. Miąższość pokrywy lodowej pozostaje w zależności od czasu jej występowania. Szybkość przyrostu grubości pokrywy lodowej zmieniała się od 0,296 cm/d do 3,6 cm/d. Nie stwierdzono wpływu usuwania hypolimnionu na długość okresu występowania oraz miąższość pokrywy lodowej. Długość okresu występowania pokrywy lodowej wpływa na czas trwania cyrkulacji wiosennej. Ma zatem wpływ na bilans tlenowy ekosystemu limnicznego.