Morphometry changes of Lake Ostrowskie (the Gniezno Lakeland) on the basis of cartographic, remote sensing and geodetic surveying

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Abstract. The authors studied changes in the morphometry of Lake Ostrowskie over the period of 123 years on the grounds of cartographic materials, remote sensing data, land surveying, and data referring to the water stages. The changes that occurred in the lake up to the 1960s were related to the regulation and melioration works conducted in the entire area of the Gniezno Lakeland. On the other hand, drainage of the open pits of brown coal resulted in the considerable decline of the water table by another 2.5 m in the years 2002-2009. As a result of the decline of water down to 96.4 m a.s.l. the present lake was divided into two water bodies (the eastern one and the western one) joint with a channel. This led to the decline in the lake area from 346.7 ha in 1887 to 242.0 ha, and its volume by 28.9%, out of which by 18.3% only in recent twenty-eight years.

Key words: lake, morphometry, temporal change, GPS, aerial photographs

Introduction

Lakes have evolved due to several stages of transformations, and at present they are at a different phase of the development of their basins. The evolution of the basins of postglacial lakes began when dead ice blocks had melted away, which in the case of most Polish lakes took place in the Allerød, and more seldom in the Bølling. The pace of the transformations of the lake basin from the moment of its formation to the present times strongly fluctuated. Two major factors were of importance, namely: level changes (the decline) of lake waters and accumulation of biogenic and terrestrial deposits in the basin. The lake basin has been systematically filled as a result of sedimentation and sedimentation processes, which also leads to the further decline of the lake volume.

Another type of changes covers the recent 250 years, and is related to anthropogenic activity. This interference has resulted in considerable transformations, concentrated in a relatively short period of time. These changes are very noticeable when exploitation of minerals begins.

The Holocene record of the development of many lakes in Poland indicated that the water level

at that time had varied and had been influenced by climatic factors most frequently (Lake Biskupińskie, Gościąż, Weneckie, Gąsawskie, Pakoskie, Gopło). These were long-term fluctuations which lasted for tens, hundreds and even thousands of years. On the other hand, the present fluctuations are of a short-term character (seasonal, yearly or for some years only), and they tend to decline constantly. It is generally assumed that the average degree of the decline of the lakes related to the Weichselian glaciation is around 65-75%, whereas, only in the years 1954-1992, the number of lakes decreased as much as by 2 215, i.e. 11.2% of their area (Choiński 2007).

The "Dutch colonisation", which started to develop intensely from the end of the seventeenth century, brought about regulation of rivers and melioration of water-logged areas, concentrated mainly in the Noteć and Odra river valleys. The regulation works mainly involved drainage of water-logged areas, straightening river channels, canalization of many fragments of rivers and joining closed lakes into open systems. These works resulted in lowering of the water tables in many lakes of the Wielkopolska Lowland by 0.6-0.8 m on average, or in more extreme cases even by 1.1-1.4 m. Such a considerable interference brought about the

decline of the lake area by several, or in more extreme cases by 80 percent (Kaniecki 1997). The lowering of the water table level also resulted in the decline of the lake volume. As Choiński (2001) points out the area of Lake Jamno decreased by approximately 150 ha over 70 years of the twentieth century, whereas its volume fell down by 9 247 dam³, ie. by 22.7%.

Mineral exploitation conducted in Poland since the latter half of the eighteenth century caused considerable changes in the natural environment (Sawicki and Gutry-Korycka 1993). This is particularly noticeable with respect to brown coal open pits whose extraction requires drainage of the area surrounding a particular open pit. Deep depression sinks of various extent develop as a result of that drainage, depending upon the amount of pumped out water. One of the well-documented examples can be seen in the area of the Bełchatów brown coal mine, which is located in the catchment of the River Widawka, the right-side tributary of the River Warta (Wachowiak 2005). The areas of the “Konin” and “Pątnów” mines located in the catchment of the Warta-Gopło Channel, where several lakes (Gosławskie, Pątnowskie, Licheńskie, Mikorzyńskie and Ślesieńskie) are located, can serve as other examples. The system of formation drainage in this area brought about forced water infiltration from Lake Gosławskie, causing a six-time bigger increase of water infiltration from Lake Gosławskie with concurrent lack of underground inflow to the lake (Paślawski 1968).

Another example of the influence of anthropopressure upon the water table can be seen in the transformations which have taken place in Lake Gopło in recent 238 years. Regulation works conducted in the Noteć river channel in the years 1775-1878 and melioration procedures in its upper section resulted in the decline of the water table in the lake by approximately 3.3 metres. The basin of the present lake covers only the deepest parts of the former water body, ie. merely 19.2% of the lake area observed before 1772, and 28.1% of its former volume (Dorożyński and Skowron 2002).

This work shows the consequences of mine draining and its influence upon water relations in the lakes located in the eastern part of the Gniezno Lakeland. The water level in the lakes has considerably declined since 2002 as a result of the Konin Brown Coal Mine operation. In the years 2002-2005 the water table in the water bodies fell down dramatically even by 2 metres. Such changes result in the decline of their value of even 22.9% (Marszelewski and Radomski 2008). This

problem concerns six lakes: Budzisławskie, Powidzkie, Suszewskie, Wilczyńskie, Wójcińskie and Ostrowskie, located in the eastern part of the Gniezno Lakeland (Fig. 1).

Lake Ostrowskie and the catchment of the Ostrowo-Gopło Channel are located in the eastern part of the Gniezno Lakeland which belongs to the macro-region of the Wielkopolska Lakeland. It borders with the Chodzież Lakeland in the north, with the Poznań Lakeland in the west, with the channel of Lake Gopło in the east, and with the Wrzesińska Plain in the south.

Lake Ostrowskie was drained through the Ostrowo-Gopło Channel which in recent six years has become an episodic stream. The direct catchment of the lake amounts to 10.3 km³. Forests cover 67% of its area, farming lands 26.1%, and grassland and other forms take approximately 6.9%. Several streams flow into the lake, out of which the inflow from Lake Kownackie is a regular watercourse.

This study intends to determine what changes have taken place in Lake Ostrowskie through the analysis of morphometric properties of its basin on the grounds of the collected archival cartographic materials, remote sensing data, and direct surveying.

The application of cartographic and remote sensing methods in the examination of temporal changes of the shorelines can be found in several scientific works concerning both Polish and world water bodies. These works have accounted for panchromatic and colourful aerial photographs and satellite images (Serafin 2008; Aleskeikh et al. 2007; Rongxing et al. 2001).

Materials and investigation methods

The archival cartographic materials, remote sensing data and the results of land surveying with the use of GPS receiver were applied to the research (Table 1). The time span of the study is delimited by two stages – the oldest coming from the topographic map (the so-called *Messtischblätter*) at the scale 1:25 000 made in 1887 (the sheet Gembitz published by *Preuß. Landesaufnahme*) and the latest coming from the detailed field exploration conducted in 2009 with the use of GPS surveying receiver.

Desk studies were connected to the construction of a complete geographic information system, whose fundamental information layers included the archival topographic maps and multitemporal aerial photographs. All the original materials were scanned and

Fig. 1. Location of the lakes and the open pits of the Konin Brown Coal Mine: 1 – Lake Ostrowskie, 2 – other lakes, 3 – limits of the existing open pits, 4 – limit of the depression sink, 5 – watershed, 6 – directions of groundwater runoff, 7 – direction of the river outflow, 8 – direction of the water pumped out from the open pits (according to Orłowski and Ilnicki 2007)

Table 1. The list of used cartographic and remote sensing materials

No.	Items	Scale	Validity
1	A German topographic map, sheet 1865 (Gembitz)	1:25 000	1887
2	A German topographic map, sheet 3474 (Gembitz)	1:25 000	1911
3	A bathymetric plan of the lake, Institute of Inland Fisheries	1:5 000	1960
4	A topographic map, the so-called "poviat map", Topographic Board SG WP	1:25 000	1964
5	Panchromatic aerial photographs, no data about the precise date of the flight	1:30 000	1980
6	Topographic maps: 364.441, 364.442, 364.443, 334.444, 374.222	1:10 000	1981
7	Panchromatic aerial photographs, no data about the precise date of the flight	1:27 000	1991
8	Colourful aerial photographs taken on 11th August 1996	1:26 000	1996
9	Panchromatic aerial photographs taken on 14th April 2004	1:26 000	2004
10	Direct GPS measurements – Leica GPS GX 1230 taken on 19th February 2009	n/a	2009

calibrated with the Polish National Coordinate System 1992. The calibration of all the aerial photographs and topographic maps was conducted in respect of situation details found in the topographic map at the scale 1:10 000, which was made in 1891. The calibration error of the applied scans of the topographic maps, plans and aerial photographs did not exceed the accuracy degree of their originals. This made it possible to obtain cartometric raster images, which in subsequent

stages of work could be compared with one another. The source materials prepared in such a way allowed the authors to carry out vectorization of the shoreline of Lake Ostrowskie. In this way the authors established nine outlines of the shoreline from the following periods: 1887, 1911, 1960, 1964, 1980, 1981, 1991, 1996, and 2004. The determination of the boundary of the shoreline made it possible to define the entire area of the lake in the studied period.

The present outline of the shoreline was obtained through the direct measurement carried out on 19 February 2009 with the use of GPS surveying receiver Leica – GX1230 GG. The terrain coordinates were established in the Real Time Kinematic monitoring mode, and corrections of the coordinates were obtained online from the ASG-EUPOS network. This enabled the authors to achieve accuracy of the measurement of the measured point location at the scale of approx. 0.020 m in the horizontal and 0.036 m in the vertical. Altogether, 1106 terrain points were measured, out of which 839 are located in the present western part of the water body, and 277 are found in the eastern one. While determining the ordinate of the water table for the GPS measurement, the up-to-date outlines of the shoreline and the lake area were obtained. That lake area is a reference level for all the previous results (Fig. 4).

The authors also accounted for the mean annual and monthly water stage indexes in the lake in the period 1993-2009. They were shown on the water-gauge located in the eastern part of the water body. The calculations of the water volume changes were based upon the bathymetric plan of the lake made in the winter of 1960 by the Institute of Inland Fisheries in Olsztyn. The water table heights in various years (from 1887 to 2009) were determined on the grounds of the cartographic materials analyses and land surveying measurements.

The bathymetric plan became a starting point. The water stage and the lake volume were referenced to it, and moreover, the decrements or increments of water retention resources in particular years were either subtracted or added to it. A formula for the sum of cylinders was applied.

Location and hydrological characteristics of the study area

The studied area is located in the region of relatively low precipitation indexes. The mean annual sum of precipitation at the meteorological station in Gniezno recorded in the period 1951-2006 amounted to 514 mm, and varied considerably in particular years. The biggest precipitation was recorded in 1967 (789 mm), and 1961 (731 mm), whereas, the lowest precipitation values were observed in the years: 1982 (298 mm), 1959 (340 mm), and 1989 (342 mm). The course of the annual sums in the analysed period showed a positive trend at the level of $1.07 \text{ mm} \cdot \text{yr}^{-1}$, while in the years 1993-2006 there was a distinctively negative trend (Fig. 2).

The above climatic conditions influence the course of the mean annual and monthly water stages in the lake (Fig. 3). The measurements of water stages conducted in Lake Ostrowskie showed that in the years 1993-1998 the mean water level had remained at the level of 97.45 m a.s.l. and had been by approximately

Fig. 2. The course of the annual sums of precipitation (mm) at the meteorological station in Gniezno and the trend line in the years 1951-2006 (prepared on the grounds of the data obtained from the Institute of Meteorology and Water Management)

Fig. 3. The mean annual location of the water table in Lake Ostrowskie during the period 1993-2009 (prepared on the grounds of the data obtained from the Institute of Meteorology and Water Management)

1.3-1.5 m lower than the one in the 1960s. From 1999 the water level rose by 0.6 m (98.03 m a.s.l.), and after 2004 it declined again by 0.5-0.6 m (97.01 m a.s.l.). Particularly significant changes occurred in 2005 when the water level declined down to 96.55 m a.s.l. A passive hydrological character of Lake Ostrowskie mainly results from the low index of water exchange ($\alpha = 0.29$) to 2003, and the small annual amplitude of water stages.

Results and discussion

Similarly to other lakes located in the area of the last glaciation, Lake Ostrowskie has undergone significant changes due to increasing anthropopressure.

The analyses of available cartographic materials and remote sensing data and surveying measurements confirm the investigations carried out by other authors (Niewiarowski 1978; Choiński 2001; Dorożyński and Skowron 2002; Marszelewski 2005), who conclude that the level of the water table in many Polish lakes has considerably declined for over 120-130 years. This also refers to the lakes located in the Gniezno Lakeland, including Lake Ostrowskie in particular.

As a result of regulation works conducted in the upper catchment of the Noteć River before 1887 the water level declined in Lake Ostrowskie and got stable at 99.0-100.0 m a.s.l. The lake's area determined on the grounds of the maps from 1887 amounted to 346.7 ha. A significantly lower area characterizes the lake in the

map which was made in 1911 (313.5 ha). The water table in the lake remained at 99.0 m a.s.l. It should be remembered that after the catastrophic flood in the area of the upper Noteć in the years 1854-1855 the water level in Lake Gopło was decreased by 1.4-1.5 m (78.3 m a.s.l.). At the same time the Ostrowo-Gopło Channel was dug to be used for local sailing purposes. The level of the water table in Lake Ostrowskie may have been at 99.5-100 m a.s.l., which guaranteed the outflow of waters to Lake Gopło and free sailing. However, there is no irrefutable evidence which could confirm functioning of the lake at such a level.

Another stage covers a relatively peaceful period and concerns the first half of the twentieth century (1911-1960). The bathymetric plan of the lake made by the Institute of Inland Fisheries in Olsztyn in February 1960 and the authors' other direct observations point to the minimal hydrological changes in the lake system.

Considerably bigger changes occurred as late as in the 1980s, and were brought about by low precipitation and melioration works conducted in the lower catchment of the Ostrowo-Gopło Channel at that time. The outflow from the lake declined significantly. The lake's water table gets lowered down to 98.5 m a.s.l., while its area decreases to 282.9 ha (32%), and its volume amounts to 4.8%. The shoreline also lengthens noticeably.

Bigger changes can be observed only after 1992. At this time the lakes located in the southern part

Fig. 4. The area of Lake Ostrowskie in 2009 on the background of: A – lake area in 1887, B – lake area in 1911, C – lake area in 1981, and D – lake area in 2004

of the Gniezno Lakeland stayed within the range of the depression sink of the Konin Brown Coal Mine. The investigations carried out in the years 1995-2006 proved that all the lakes located in the depression sink showed that their water table levels declined as early as in the years 1992-1993 (Ilnicki 1996, Ilnicki and Orłowski 2006, Orłowski and Ilnicki 2007). Yet, violent decreases in water stages occurred after 2000 (Lake Suszewskie and Wilczyńskie), and in other lakes after 2003.

The data in Table 2 indicate unambiguously that the level of the water table in all the lakes located in the eastern part of the Gniezno Lakeland has gone down by 0.32-2.53 m for the last 28-30 years.

A considerable decline in the water level in all the lakes was observed in the years 2002-2005, when the mean water stage declined by 0.4 m in Lake Powidzkie, 0.8 m in Lake Budziszławskie, 1.0 m in Lake

Wilczyńskie, 1.5 m in Lake Wójcińskie and Lake Suszewskie, and by 1.4 m in Lake Ostrowskie. This resulted in the decrease of water resources in these lakes by 3.4-22.9% (Marszelewski and Radomski 2008).

Changes in the lake's area and the elements referring to the form of the lake basin are the measurable consequences of the decline of the water level. The area of the water table in Lake Ostrowskie diminished by nearly 105 ha, ie. by 30.2%, in the years 1887-2009. The pace of that change varied, though (Table 3). Changes in the lake volume were of a similar character. The volume decreased by 28,9% in the years 1887-2009, while as much as by 18.3% in the last 28 years.

The falling lake volume exposed new areas, particularly shallow-water ones, yet mainly it caused big changes in the selected sub-aquatic elements. The shoreline altered significantly, which could be seen in the selected periods as compared to its extent in 2009

Table 2. Changes in the water stages in the selected lakes located in the borderland between the Gniezno and Kujawy Lakelands in the years 1960-2005 (according to Orłowski and Ilnicki 2007, partially changed)

Lake	Area [ha]	Mean annual water level in [m a.s.l.] in a hydrological year				Water level decline in the years 1965-2005
		1965	1994	2000	2005	
Niedzięgiel	602.5	104.00	103.10	03.49	103.12	-0.88
Powidzkie	1 097.5	98.35	98.04	98.18	97.96	-0.32
Budziszławskie	157.5	99.40	98.41	98.60	97.83	-1.57
Suszewskie	205.0	99.20	97.89	97.78	96.67	-2.53
Wilczyńskie	87.5	99.00	97.71	98.08	96.69	-2.31
Wójcińsko-Kownackie	237.5	98.90	97.86	98.07	97.50	-1.40
Ostrowskie	315.0	98.90	97.37	98.05	97.47	-1.43
Skulskie	120.0	85.90	86.14	86.01	85.92	+0.02
Gopło	2 121.5	76.82	76.89	76.69	76.59	-0.23

Table 3. Percentage share in the changes in the area and volume, and the pace of those changes in Lake Ostrowskie in the years 1887-2009

Year	Water table index [m a.s.l.]	Lake area				Lake volume		
		in ha	Change of the area in ha	Percentage of the change in relation to the previous period	Pace of the change in ha·yr	in dam ³	Percentage of the change in relation to the previous period	Pace of the change in dam ³ ·yr ⁻¹
1887	99.9	346.7				34 526.3		
1911	99.0	313.5	-33.2	-10.6	-1.4	31 555.4	-8.6	-123.8
1960	98.9	314.5	+1.0	+0.3	0.0	31 242.9	-1.0	-6.4
1981	98.5	282.9	-32.1	-11.3	-6.4	30 057.1	-4.8	-56.5
1996	97.37 ^a	270.0	-12.9	-4.6	-0.9	26 933.1	-10.4	-208.3
2004	97.47 ^a	279.1	+9.1	+3.4	+1.1	27 207.7	+0.9	+34.3
2009	96.4	242.0	-37.1	-15.3	-7.4	24 545.6	-18.3	-196.8

(Fig. 4). At present Lake Ostrowskie is composed of two water bodies divided by a wide dyke, which was artificially dug to create a channel that is 70 m long and 2-3 m wide. The western part is of a narrow channel character (approx. 6.5 km long and up to 0.4 km wide) and has a series of consecutive kettle lakes. Whereas, the eastern one constitutes a large water body which is approximately 0.9 km wide and has a centric net of isobaths and a wide littoral zone (Fig. 3).

The character of the changes in the parameters referring to the sub-aquatic features of the lake basin (the mean depth, depth index, and the lake basin permanence index) are presented in Table 4. This is particularly noticeable while analyzing the parameters which describe the relationship between horizontal and vertical dimensions of the lake basin (a depth index – c , a relative depth index – C_R) (Skowron 2004).

Conclusions

The long-term exploitation of brown coal in this region required lowering of waters in the Tertiary-Cretaceous layer by 60-70 m (the Pątnów open pit exploited in the years 1962-2001 reached the depth of 59 m, Józwin IIB open pit exploited in the years 2004-2020 has the average depth of 70 m). According to Orłowski and Ilnicki (2007), there may be hydraulic windows in the vicinity of Lake Suszewskie and Wilczyńskie, thanks to which there is runoff of surface waters to the lower levels.

The decline of waters in these lakes, which is an effect of forced infiltration (the lowest water level above the sea level), causes the inflow of the waters from other lakes into them. This is confirmed by the directions of surface waters outflow between those water bodies.

The increase of pumped out water in 2004 and 2005 caused an immediate consequence related to the decline of the water table in all the lakes of this region. The amount of water drained from the Józwin IIB open pit ranged from 14.41 hm³ in 2000 to 26.84 hm³ in 2005 (Ilnicki and Orłowski 2006). Mining water coming from drainage is directed to Lake Goślawskie and Lake Ślesińskie. In 2003 the 150-year outflow of waters from Lake Ostrowskie through the Ostrowo-Gopło Channel to Lake Gopło, which is located 11 km away, stopped.

Exposure and destruction of the littoral zone, an important element in the food link of this ecosystem, appear the negative consequences of the water decline in Lake Ostrowskie. According to Ilnicki (1996), in order to improve and rescue this unfavourable hydrological situation in the above mentioned lakes, it is vital to direct the pumped out waters to Lake Budziśławskie and Skorzęcińskie.

The decision to direct the water pumped out from the Józwin IIB open pit into two lakes: Budziśławskie and Wilczyńskie through an eight-kilometre pipeline seems promising. In such a way partial realimentation of water relations can be undertaken. The costs are to

Table 4. Changes in morphometric parameters of Lake Ostrowskie in the years 1887-2009

No.	Year	Water table index [m a.s.l.]	Lake area A [ha]	Length of the shoreline L [km]	Development of the shoreline D_L	Maximum depth of the lake z_{max} [m]	Mean depth of the lake z_m [m]	Lake depth index W_g	Basin permanence index acc. to Kerekes T	Depth index acc. to Filatova c	Relative depth index C_R
1	1887	99.00	346.7	19.0	2.88	35.2	9.12	0.26	1.66	69.3	18.0
2	1911	99.00	313.5	19.9	3.17	35.2	10.06	0.29	1.59	76.7	21.9
3	1960	98.90	314.5	19.9	3.17	35.1	9.93	0.28	1.57	75.9	21.5
5	1981	98.50	282.9	21.0	3.52	34.7	10.62	0.31	1.43	83.4	25.5
7	1996	97.37 ^a	270.0	20.5	3.52	33.6	9.98	0.30	1.31	84.6	25.1
8	2005	97.47 ^a	279.1	20.9	3.52	33.7	9.75	0.29	1.30	82.1	23.8
9	2009	96.40	242.0	20.1	3.64	32.6	10.14	0.31	1.22	91.6	28.5

Explanation: $D_L = L/2\sqrt{\pi P}$, $W_g = z_m/z_{max}$, $T = V/L$, $c = (z_{max}/B_m) \times 10^{-3}$ where B_m is lake mean width in meters, $C_R = (z_m/B_m) \times 10^{-3}$, ^a – the mean annual water level in the lake according to Orłowski and Ilnicki 2007

be shared among the Voivodeship Fund for Environmental Protection, the Kujawsko-Pomorski Marshal's Office and the gminas interested in this problem.

The archival cartographic materials and remote sensing data are a very valuable information source of the lake's past, its condition and its properties. In the connection with modern spatial data processing methods they constitute an excellent base for comparative analyses, including studies of the changes in the morphometry of the lakes.

The ASG-EUPOS system launched on 2 June 2008 accounts for fast and very precise single measurements with the use of GPS receivers, which boosts the possibilities of its applications to similar works in a crucial way, and also contributes to more frequent monitoring of the selected water bodies.

The precise measurement of the location of the lake's shoreline is now possible regardless of a season. The present condition registered with great accuracy will constitute a reference point for future field explorations. In future it will be possible to conduct investigations with approximate accuracy on the grounds of present photogrammetric flights, where a terrain pixel may reach the size of even 10 cm.

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