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Assessment of the Impact of a Dammed Reservoir on Groundwater Levels in Adjacent Areas Based on the Przebędowo Reservoir

Błażej Waligórski[1], Mariusz Korytowski[2], Piotr Stachowski[2], Krzysztof Otremba[2], Karolina Kraczkowska[2]*
[1]State Water Holding Polish Waters;
Regional Water Management Authority, Poznań, Poland
[2]Poznań University of Life Sciences, Poland
[*]corresponding author's e-mail: mariusz.korytowski@up.poznan.pl

1. Introduction

At present the term water management is used to refer to the process of water storage, use and protection, the removal of its excess and limitation of the resulting threats, as well as alleviation and elimination of water shortages (Kaca et al. 2011). As it was reported by Mioduszewski (2012) and Przybyła et al. (2014), water resources, modified mainly by precipitation and evapotranspiration, are characterised by considerable spatial and temporal variation, resulting in periods of deleterious water scarcity or floods causing considerable losses in river valleys.

One of the methods applied to counteract these adverse phenomena is connected with the construction of retention reservoirs, frequently located either in the river continuum (such as dam reservoirs) or outside it (lateral). According to Puczyńska and Skrzypski (2009) as well as Szczykowska and Siemieniuk (2011), water retention in dam reservoirs contributes to a considerable improvement of water balance. However, once water is dammed in retention reservoirs we may observe a certain change in the hydrologic conditions in the water systems. It frequently consists in a reduction of the fluctuations in river water stages and flows, as well as an increased depth of groundwater tables and soil moisture in the immediate vicinity of reservoirs (Górniak and Piekarski 1999, Król et al. 2010).Changes in hydrogeological conditions caused by damming structures within their impact zones may be beneficial, neutral or adverse (Michalec 2012). The intensity of changes caused by the constructed dam reservoir depends on the relief of the surrounding area, the size of the reservoir and primarily its capacity.

The higher the shores, the faster this impact declines, while the greater the mass of retained water, the farther its impact is extended (Traczewska 2012).

According to Zieliński (2015), knowledge on the mechanisms of function in anthropogenically transformed, lowland aquatic ecosystems under various hydrometeorological conditions is still insufficient, particularly in the context of sustainable water management, wherever the probability of hydrological stress in high.

The aim of this study was to assess the impact of the Przebędowo dam reservoir on the groundwater tables in adjacent areas after three years of its operation.

2. Material and methods

This paper presents results of studies conducted in 2015, 2016 and 2017 hydrological years in the catchment of the Przebędowo reservoir (in the areas adjacent to the reservoir) located in the Wielkopolskie province, 25 km north of Poznań in the Murowana Goślina commune (Fig. 1).

In terms of the physico-geographical regionalisation of Poland (Kondracki 2000) the study area of early postglacial landscape is located in the Wielkopolskie Lake District in the area of the Poznań Warta Gorge (315.52). In the discussed catchment of approx. 100 km^2 forests predominate, while to a lesser extent arable land is found in the area adjacent to the reservoir.

Overall the areas adjacent to the reservoir are composed of quaternary (Pleistocene) fluvial deposits, while the analysis of layers within piezometers showed a predominance of medium sands up to a depth of approx. 3m, with mean porosity of 36%, in which groundwaters form a continuous phreatic aquifer.

The analysed reservoir was established in the valley of the Trojanka river (from 6+915 km to 8+371 km of its course), being a depositional terrace with its slope towards the reservoir shores. It was constructed by the Greater Poland Provincial Land Drainage and Water Units Board in Poznań and put into operation in November 2014. The reservoir is located at 52°34'28"northern latitude and 17°00'33" eastern longitude. The earth dam of the reservoir is class IV it is 334 meters long and 3.30 meters high. The reservoir with a length of 1450 m and a maximum bed-width of 120 m at a normal pool level with an elevation of 72.5 m a.s.l. has a mean depth of 0.94 m and a flooded surface of 12.03 ha (Table 1). Around the reservoir an ecological buffer zone, the so-called transition zone between the reservoir and the surrounding utilised agricultural areas, with a mean width of approx. 13, was established as grassland with tree and shrub plantings. The role of this buffer zone is to reduce runoff of biogenic compounds and pesticides from adjacent agricultural areas.

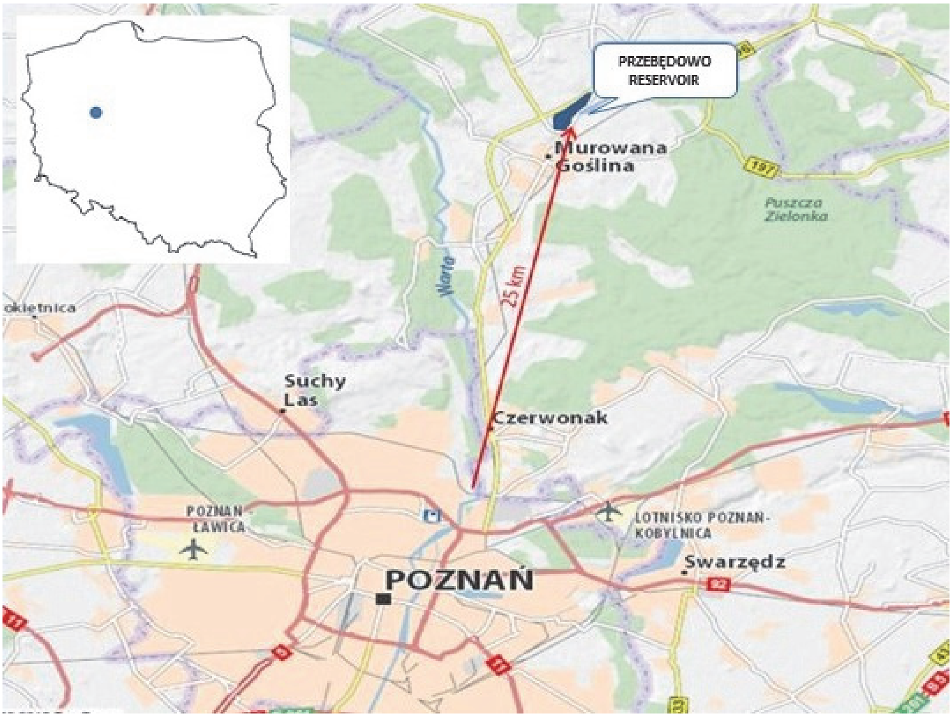

Fig. 1. Location of the Przebędowo reservoir in the Wielkopolskie province

Water levels in the reservoir were measured using a staff gauge located in the damming structure at the outflow of the reservoir (Fig. 2). Additionally water levels in the reservoir were recorded continuously using a hydrostatic probe, from which recorded data were sent to the telemetric module installed at the spillway tower.

In turn, groundwater levels were measured in 21 wells established in seven section lines in the immediate vicinity of the reservoir. Analyses were conducted for data recorded in 7 selected wells: no. P-2 and no. P-3 located in the area adjacent to the reservoir from the west and from no. P16 to. P18, as well as nos. P-20 and P-21 installed from the east. The other wells established during the reservoir construction works were not included in this study due to their location in the dam crest.

In the water year 2015 from mid-January a monitoring system was initiated in the discussed structure; for this reason the characteristics of water levels cover the period since that time point.

Further analysis was expanded to include data from six additional wells installed in April 2016, i.e. wells nos. 1’, 2’, 3’, 4’, 5’ and 6’, in terms of the elevation to the national grid and located in the area adjacent to the reservoir at a distance of approx. 10 m from its shores in three representative cross-sections (Fig. 3).

Water levels in the analysed years were measured once every two weeks. In turn, weekly water levels in the investigated wells were recreated by calculating mean values from the levels measured at 2-week intervals.

The number of days when groundwaters were fed by the water retained in the reservoir was determined in the analysed period based on the difference between the elevation of waters in the reservoir and those of groundwaters in the wells included in the study. Estimate of essentiality relations between water levels in reservoir and groundwater levels in analysed wells carried T-students method.

Table 1. Basic parameters of the Przebędowo retention reservoir

No.	Parameter	Unit	results
1	Structure class (earth dam)	class	IV
2	Length	m	1450
3	Maximum width	m	120
4	Shoreline length	m	2980
5	Pool levels: a/ Max. pool level (at $Q_{K0.5\%}$) b/ normal pool level c/ minimum pool level	 m a.s.l. m a.s.l. m a.s.l.	 73.00 72.50 71.50
6	Reservoir capacity: - maximum at max. pool level - total at normal pool level V_c - active capacity V_U - dead at min. pool level V_m	 m^3 m^3 m^3 m^3	 229 450 162 350 113 350 49 000
7	Flood control capacity between normal damming and maximum pool levels	m^3	67 100
8	Mean reservoir depth at: normal pool level minimum pool level	 m m	 0.94 0.38
9	Reservoir area: - normal pool level - minimum pool level	 ha ha	 12.03 10.64

Fig. 2. A staff gauge with a hydrostatic probe installed at the damming structure at the outflow from the reservoir

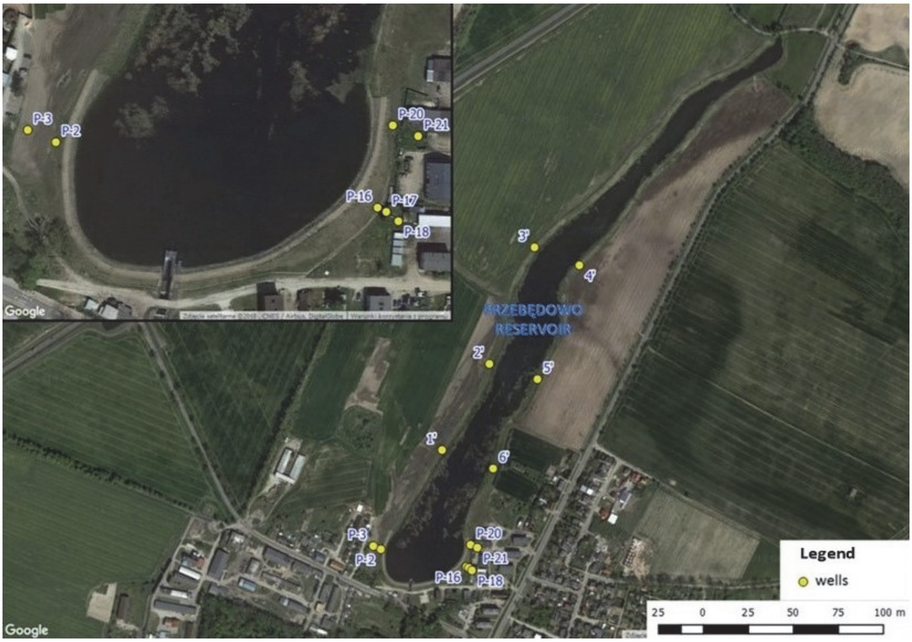

Fig. 3. Location of wells measuring groundwater levels in the area adjacent to the reservoir (source: the authors' study based on Google Earth – https://www.google.pl/intl/pl/earth/)

Results of water level observations in the investigated structure were used by permission of the Director of the former Wielkopolska Board of Land Amelioration and Water Facilities (at present State Water Holding Polish Waters; Regional Water Management Authority in Poznań).
Meteorological conditions in the investigated water years (precipitation and air temperature) in relation to the multiannual means of 2000-2015 were characterised based on the data recorded in the weather station of the Experimental and Teaching Station of the Forest Arboretum in Zielonka, located approx. 8 km south-east from the discussed reservoir. The station is located in the central part of the Puszcza Zielonka Forest at 91.00 m a.s.l., at 52°33′00″ northern latitude and 17°06'33" eastern longitude. It is situated approx. 24 km from the nearest station of the Institute of Meteorology and Water Management in Poznań Ławica (Grajewski 2013).

The characteristics of moisture conditions for the analysed water years was conducted according to Kędziora (1995, after Kaczorowska 1962) taking into consideration criteria contained in Table 2.

Table 2. Characteristics of moisture conditions in hydrological years

Type of year	% normal precipitation
Extremely dry	below 50
very dry	50-74
Dry	75-89
Average	90-110
Wet	111-125
Very wet	126-150
Extremely wet	over 150

This study included also documentation from the execution of geological works connected with the installation of piezometers in the Przebędowo small retention reservoir (2014) prepared by Geoprogram (W. Andrzejewski, R. Urban), the Water utility and water rights report (2009) and the Water management guidelines (2009), as well as the Detailed design of the Przebędowo reservoir (2011) prepared by Biuro Projektów Wodnych Melioracji i Inżynierii Środowiska „BIPROWODMEL" from Poznań.

3. Results and discussion

As it was reported by Bąk (2003), the Wielkopolska region is considered to be one of the driest and warmest regions of Poland. Polar-maritime air masses predominate over the area; as a result the summers are cooler and the winters are warmer when compared to the eastern, more continental part of Poland. Most frequently cold fronts move over the region and in the summer season they are often accompanied by storms, considerable fluctuations in temperature and increased wind speeds. Mean annual atmospheric pressure is approx. 1005 hPa – it is lowest in the spring (in April), slightly higher in the summer, while it reaches the maximum in the autumn (in October). According to that author one of the characteristics of the Wielkopolska climate is also related with the frequent, although irregular occurrence of precipitation-free periods, which has a negative effect on plant growth. In the 20-year period of 1981-2000 the long-term precipitation-free periods (lasting over 30 days) appeared in 9-year intervals. Precipitation-free periods were observed both in dry, average and wet years. The largest numbers of days with precipitation were recorded in the winter, whereas the greatest precipitation totals are observed in the summer.

The first hydrological year analysed in this study (2015) was a dry year, in which precipitation total was 429 mm and it was by 131 mm lower than the multi-annual mean at air temperature exceeding the mean by 0.5°C (Table 3). Both the winter and summer half-years of the discussed year, in which precipitation totals were lower than the multi-annual means by 54 mm and 77 mm, respectively, were classified as dry.

Table 3. Half-year and yearly precipitation totals (P) and mean air temperatures (t) in 2015, 2016 and 2017 hydrological years and their deviations from means of the multi-year period of 2000-2015

Period	precipitation P (mm)			Temperature t (°C)		
	winter XI-IV	summer V-X	year XI-X	winter XI-IV	summer V-X	year XI-X
Multi-year mean	**229**	**330**	**560**	**2.6**	**15.4**	**9.0**
2015	175	253	429	3.8	15.3	9.5
Deviation	**-54**	**-77**	**-131**	**1.2**	**-0.1**	**0.5**
2016	219	463	682	4.1	15.7	9.9
Deviation	**-10**	**133**	**122**	**1.5**	**0.4**	**0.4**
2017	211	593	804	2.5	15.6	9.1
Deviation	**-18**	**263**	**244**	**-0.1**	**0.2**	**0.1**

In turn, the hydrological year of 2016 was a wet year, in which the precipitation total was 682 mm and it was by 122 mm higher than the multi-annual mean, at air temperature exceeding the mean by 0.4°C. The winter half-year of that year with the precipitation total by 10 mm lower than the multi-annual mean and air temperature by 1.5°C higher than the mean was average and warm. In turn, the summer half-year of the discussed year was very wet, at the precipitation total exceeding the mean by 122 mm, at air temperature by 0.4°C higher than the mean.

The last hydrological year analysed in this study, i.e. 2017, was very wet, since precipitation total in that year exceeded the multi-annual mean by as much as 244 mm, at air temperature close to the mean. The winter half-year of that year, in which precipitation total was 211 mm and by 18 mmm lower than the mean, was average. In contrast, the summer half-year was extremely wet, since precipitation total in that half-year was 593 mm and exceeded the multi-year mean by 263 mm, at air temperature exceeding the mean by 0.2°C.

In the winter half-year of the first year analysed in this study, on 18 February the water elevation in the reservoir reached the maximum (72.49 m a.s.l.), which was maintained until 13 April (Fig. 4). In turn, groundwater levels in the analysed wells on that day reached values ranging from 70.72 m. a.s.l. (well P-21) to 71.7 m a.s.l. (well P-3) and it continued to increase. On 7 April maximum groundwater elevations in the investigated wells were recorded and they ranged from 70.85 m a.s.l. (well P-21) to 71.87 m a.s.l. (well P-3). From mid-April to the end of the analysed winter half-year the water table in the reservoir was dropping, while the groundwater tables in the adjacent area showed no greater variability. At the end of this half-year the water pool in the reservoir reached the elevation of 72.39 m a.s.l., while groundwater levels ranged from 70.85 m a.s.l. (well P-21) to 71.85 m a.s.l. (well P-3). From the beginning of the summer half-year of 2015, which in terms of moisture conditions was dry, both the water pool in the reservoir and groundwater levels in the adjacent area were decreasing. The lowest levels of reservoir water and groundwaters were recorded in the beginning of September. The water pool in the reservoir in that period was 71.89 m a.s.l. and it was 61 cm below the normal pool level, while the elevation of groundwaters in the analysed wells ranged from 70.65 m a.s.l. (well P-21) to 71.52 m a.s.l. (well P-3). A considerable effect on this situation was exerted by the adverse course of weather conditions, particularly low precipitation totals and high air temperatures in August. At the end of the discussed half-year, after total precipitation of 30 mm an increase was recorded in the water pool in the reservoir and in the analysed wells, the water pool in the reservoir was 72.26 m a.s.l., while groundwater elevations ranged from 70.7 m a.s.l. in well P-21 to 71.63 m a.s.l. in well P-3. It needs to be stated that over the entire analysed period from January to the end of October, except for the first week of observations, in which the reservoir served the drainage function, waters retained in the investigated reservoir fed groundwaters from the discussed wells, since elevations of the water pool in the reservoir were maintained over the elevations of groundwaters in the adjacent area (Fig. 4).

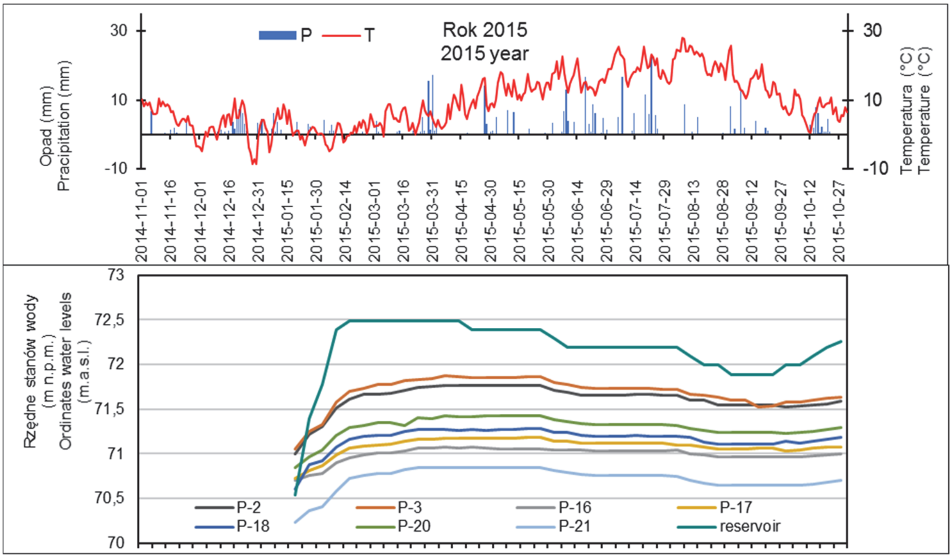

Fig. 4. Elevations of water pool in the reservoir and groundwater in analysed wells (m a.s.l.) against daily precipitation totals and mean daily air temperatures in 2015 hydrological year

In the beginning of the winter half-year of 2016 the water pool in the analysed reservoir was 72.28 m a.s.l., while the groundwater elevations in the adjacent area ranged from 70.72 m a.s.l. in well P-21 to 71.65 m a.s.l. in well P-3 (Fig. 5). Over the entire analysed half-year the water pool in the reservoir and groundwater levels in the adjacent area showed no marked variability, while their maximum values were recorded on 29 March. The water pool in the reservoir on that day reached 72.52 m a.s.l., while the groundwater levels in the area adjacent to the reservoir ranged from 70.88 m a.s.l. in well P-21 to 71.85 m a.s.l. in well P-3. It may be stated that over the entire discussed winter half-year the reservoir served the supply role, since elevations in the water levels exceeded elevations of groundwaters in the discussed wells.

Observations of groundwater levels in the additionally installed wells, i.e. wells 1' to 6', were started in the beginning of the summer half-year. The water pool in the reservoir in that period was 72.46 m a.s.l. and the groundwater elevations in the adjacent area ranged from 70.8 m a.s.l. (well P-21) to 72.96 m a.s.l. (well 5'). At the turn of May and June at low precipitation totals and higher air temperatures the water pool in the reservoir and groundwater levels in the analysed wells were observed to subside. In contrast, precipitation total of 229 mm recorded for the period from 13 June to mid-July caused an increase in water pools in the reservoir and groundwater levels. On 15 July the water pool in the reservoir reached the maximum elevation in that half-year, i.e. 72.59 m a.s.l. In turn, in some of the analysed wells the maximum pool was observed in the same day, while in some of them it was with a delay of 1 or 2 weeks and it ranged from 70.88 m n.p.m in well P-21 up to 73 m n.p.m in well no. 5’. At the end of this half-year the water pool in the reservoir had the elevation of 72.58 m a.s.l., while in the analysed wells the elevations ranged from 70.86 m a.s.l. (well P-21) to 72.89 m a.s.l. (well 5’). In the discussed half-year the elevation of the water pool in the reservoir was above those of groundwaters in most investigated wells. In turn, feeding of reservoir waters by groundwaters was observed over the entire half-year period from the area of well no. 5’, as well as wells nos. 4’ and 6’ - this time to a limited extent. Groundwaters from the side of well no. 4’ fed reservoir waters in that half-year for 63 days, while from well no. 6’ it was for 28 days.

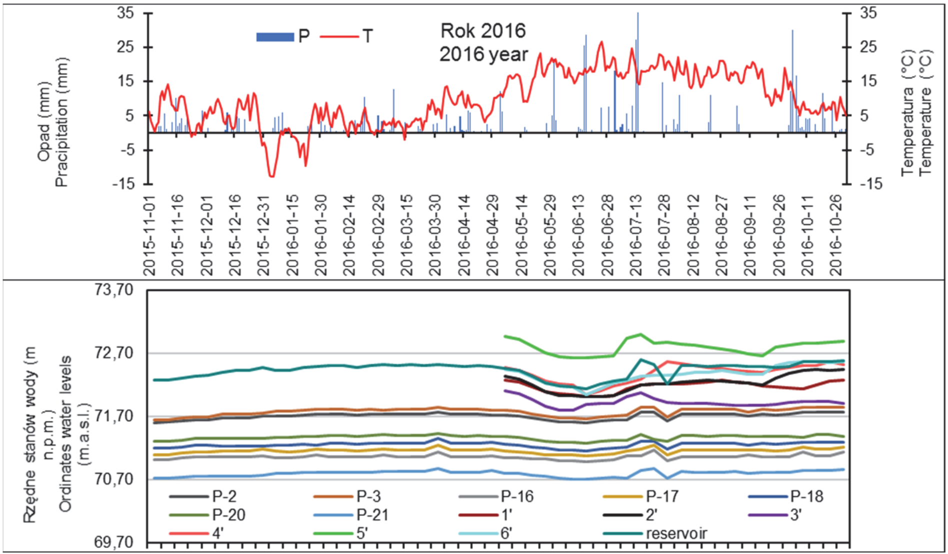

Fig. 5. Elevation of water pool in reservoir and groundwaters in analysed wells (m a.s.l.) against daily precipitation totals and mean daily air temperatures in 2016 hydrological year

In the beginning of the winter half-year of 2017 the water pool in the analysed reservoir ranged from 72.62 m a.s.l., maintained at 12 cm above the normal pool level (Fig. 6). In turn, the groundwater levels in the adjacent area in that period ranged from 70.87 m a.s.l. (well P-21) to 73.12 m a.s.l. (well 5’).

The maximum water pool in the reservoir, i.e. the elevation of 72.83 m a.s.l., was recorded in that half-year on 15 December, while groundwater levels in the adjacent area on that day reached elevations close to the maximum and ranged from 70.94 m a.s.l. in well P-21 to 73.33 m a.s.l. in well no. 5’. Over the entire analysed winter half-year (181 days) groundwaters fed the reservoir waters from the side of well no. 5’, while to a lesser extent feeding by ground-waters was also observed from wells nos. 1’, 2’, 3’, 4’ and 6’, with the feeding time ranged from 28 days (well 1’) to 112 days (well 4’). In turn, in the case of the other analysed wells, which were located closer to the damming structure, elevations of the water table were recorded below the elevations of the water pool in the reservoir and the direction of feeding was opposite. It may be stated that the recorded results were consistent, among other things, with the results of studies conducted by Głuchowska and Pływaczyk (2008) in the Odra river valley, below the Brzeg Dolny barrage, in which the authors stressed that upstream of the damming structure in its close vicinity water infiltration from the reservoir and feeding of the valley are observed.

In the beginning of the summer half-year of 2017, which in terms of precipitation was extremely wet, the water pool elevation in the reservoir was 72.59m a.s.l., while groundwater levels in the analysed wells ranged from 70.86 m a.s.l. in well P-21 to 73.32 m a.s.l. in well no. 5’ (Fig. 6).

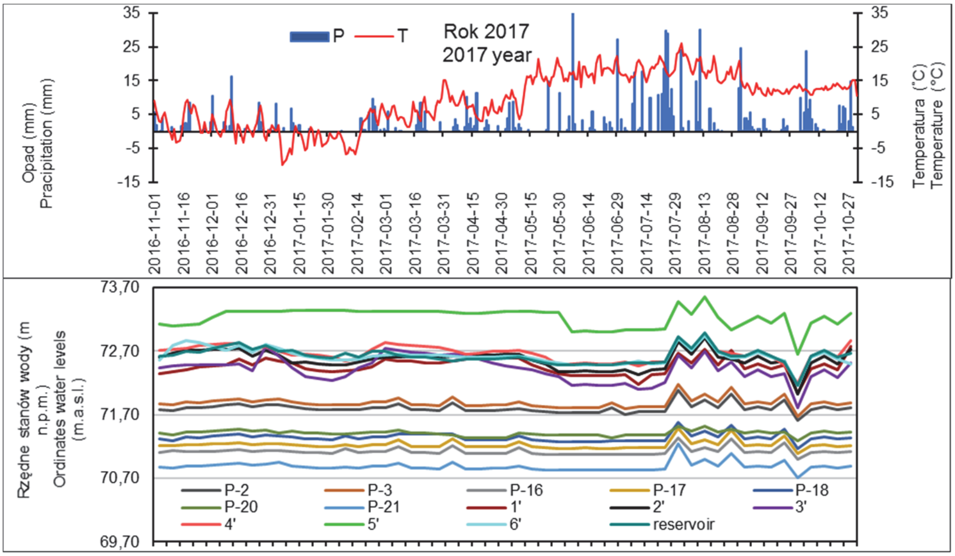

Fig. 6. Elevations of water pool in the reservoir and groundwaters in analysed wells (m a.s.l.) against daily precipitation totals and mean daily air temperatures in 2017 hydrological year

From the second decade of July to mid-August following precipitation total of 209 mm, which had been recorded in that period, an intense increase was observed in the water levels both in the reservoir and groundwaters in the adjacent area. The maximum water pool in the analysed reservoir, at the same time close to the maximum pool of 72.99 m a.s.l., was recorded on 13 August. On that day the maximum elevation was also observed for groundwaters in wells P-2'to P-6', where it reached values ranging from 72.70 m a.s.l. in well no. 3' to 73.55 m a.s.l. in well no. 5', respectively.

In turn, in the other analysed wells the maximum elevation of groundwaters was recorded two weeks earlier and ranged from 71.24 m a.s.l. (well P-21) to 72.17 m a.s.l. (well P-3). The intensive drop in the water pool levels in the reservoir and simultaneously in groundwaters in the adjacent area, which was observed in the second half of August, was not caused by the course of weather conditions, but rather by the opening of the so-called bottom outlets. This was connected with a very high water level in the reservoir, caused mainly by high precipitation totals in that period and the damming structure being jammed by vegetation debris, resulting in a threat of water overspill over the dam crest and flooding of buildings located nearby. Such actions, after Nachlik (2006), may be classified as the so-called flood prevention measure, which promotes restoration or preservation of natural outflow conditions from the catchment. These are actions facilitating limitation of flood damage in a given area and as such they are frequently applied in flood control retention facilities.

The adverse course of weather conditions observed in the second and third decades of September, particularly low precipitation total (12 mm) in that period, caused further subsidence of the water pool in the reservoir and groundwater levels in the adjacent area. The lowest water elevation in the analysed half-year was recorded on 1 October. The water elevation in the reservoir on that day was 72.16 m a.s.l., while the level of groundwaters in the analysed wells ranged from 70.71 m a.s.l. (well P-21) to 72.65 m a.s.l. (well 5').

Precipitation total of 59 mm, observed in the first decade of October caused an intensive rise in the water pool in the reservoir and the analysed wells. At the end of that half-year the water pool in the reservoir was found at 72.67 m a.s.l., while the groundwater levels reached elevations from 70.89 m a.s.l. (well P-21) to 73.29 m a.s.l. (well 5').

In the analysed summer half-year groundwaters fed reservoir waters from wells nos. 1' and 2', where the supply time amounted to 21 and 35days, respectively. Supplying the reservoir waters with groundwaters from adjacent areas was also reported from wells nos. 4', 5' and 6', while the water inflow time ranged from 49 days (well 6') to 184 days (well 5').

It may be stated that for a greater part of the analysed water years waters retained in the investigated reservoir fed groundwaters in adjacent areas, with the longest supply time ranging from 282 up to 366 days recorded for wells from P-2 to P-21 located within a close distance from the dam (Table 4).

Table 4. The numbers of days when reservoir waters were supplied by ground waters in adjacent area and ground waters in adjacent area were supplied by reservoir waters in 2015, 2016 and 2017 hydrological years

Well no.	Number of days					
	Groundwaters supplying reservoir waters			Reservoir waters supplying groundwaters		
	2015	2016	2017	2015	2016	2017
P-2	7	0	0	282	366	365
P-3	7	0	0	282	366	365
P-16	7	0	0	282	366	365
P-17	7	0	0	282	366	365
P-18	7	0	0	282	366	365
P-20	7	0	0	282	366	365
P-21	0	0	0	289	366	365
1’	-	0	42	-	366	323
2’	-	7	105	-	359	260
3’	-	0	56	-	366	309
4’	-	70	259	-	296	106
5’	-	184	365	-	182	0
6’	-	35	147	-	331	218

In turn, in the case of wells nos. 1’to 6’ located in the central area of the reservoir the waters were found to flow in both of these opposite directions. According to Radecki-Pawlik and Kapusta (2006), surface retention may not only be supplied by precipitation, but also by the soil itself, if in a porous medium such hydraulic gradients are formed, which may counter the gradient of the gravitational potential directed downward. In the analysed years groundwaters fed the reservoir waters for a period ranging from 7 days (well 2’) up to 365 days (well 5’). Recorded results are confirmed e.g. by studies conducted by Bem and Kacy (2003) in the Stawy Raszyńskie Nature Reserve, in which those authors stressed in the case of groundwaters the possible occurrence of a draining or alimentary effect of reservoirs on adjacent areas.

It needs to be observed here that the longer supply time of reservoir waters with groundwaters was recorded for wells nos. 4’, 5’ and 6’ located east of the reservoir, which may be explained by the greater supply area and influx of waters from outside the immediate catchment.

Calculations of relationships between elevations of water pools in the reservoir and elevations of groundwater tables in the investigated wells conducted for the analysed winter and summer half-years of the investigated water years in most cases showed strong dependencies. In the winter half-years of the first two years the calculated correlation coefficients ranged from 0.58 for well P-16 to 0.96 for wells P-2 and P-18 (Table 5). In turn, for the summer half-years these values ranged from 0.34 for well 3' to 0.99 in wells P-2 and P-3. It needs to be observed here that in most cases, except for the correlation for well 3', the obtained dependencies were significant at α = 0.01. As it was reported by Kala (2002), for the phenomena analysed in life sciences objective inference on strong dependencies is sufficient already at the significance level α = 0.05. In turn, in the winter half-year of the last year of the study the weakest dependencies were found between the discussed parameters. Statistically significant relationships were obtained for only six out of all the discussed wells, in which correlation coefficients ranged from 0.48 (well 2') to 0.85 (well P-20).

Table 5. Correlation coefficients (r) and significance levels (α) for relations of water levels in the reservoir with groundwater depths, in analysed wells in the adjacent area in winter and summer half-years of the 2015, 2016 and 2017 hydrological years

Well no.	P-2	P-3	P-16	P-17	P-18	P-20	P-21	1'	2'	3'	4'	5'	6'
Winter half-year of 2015													
r	0.94	0.94	0.88	0.91	0.96	0.93	0.91	-	-	-	-	-	-
α	0.01	0.01	0.01	0.01	0.01	0.01	0.01	-	-	-	-	-	-
Summer half-year of 2015													
r	0.9	0.9	0.89	0.89	0.95	0.92	0.92	-	-	-	-	-	-
α	0.01	0.01	0.01	0.01	0.01	0.01	0.01	-	-	-	-	-	-
Winter half-year of 2016													
r	0.96	0.95	0.58	0.75	0.75	0.62	0.88	-	-	-	-	-	-
α	0.01	0.01	0.01	0.01	0.01	0.01	0.01	-	-	-	-	-	-
Summer half-year of 2016													
r	0.99	0.99	0.75	0.89	0.97	0.78	0.97	0.79	0.8	0.34	0.75	0.62	0.85
α	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	-	0.01	0.01	0.01
Winter half-year of 2017													
r	0.6	0.6	0.24	0.33	0.34	0.85	0.61	0.1	0.48	0.1	0.45	0.1	0.62
α	0.01	0.01	-	-	-	0.01	0.01	-	0.01	-	-	-	0.01
Summer half-year of 2017													
r	0.74	0.74	0.61	0.64	0.73	0.9	0.74	0.79	0.94	0.89	0.94	0.81	0.97
α	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

A considerable effect on such a situation in that half-year was exerted by the below zero temperatures maintained from mid-December to the third decade of February, which could have considerably disturbed the mutual relationships between waters retained in the reservoir and groundwaters in the adjacent areas. In turn, for the summer half-year of the discussed year, similarly as in the earlier analysed summer half-years, strong dependencies were obtained, since the correlation coefficients ranged from 0.61 for well P-16 to 0.97 for well 6'(Table 5, Fig. 7) and these values were also significant at $\alpha = 0.01$.

It may be stated that apart from the course of weather conditions and relief in the immediate vicinity of the reservoir, the strong dependencies resulted also from the properties of the deposits lying in the area adjacent to the reservoir. According to Halfen and Czamary (2007) and Michalak and Nowicki (2009), hydrogeological parameters of deposits found in the escarpments and bottom of a given reservoir and its immediate vicinity, particularly porosity, to a considerable degree determine mutual dependencies between reservoir waters and groundwaters.

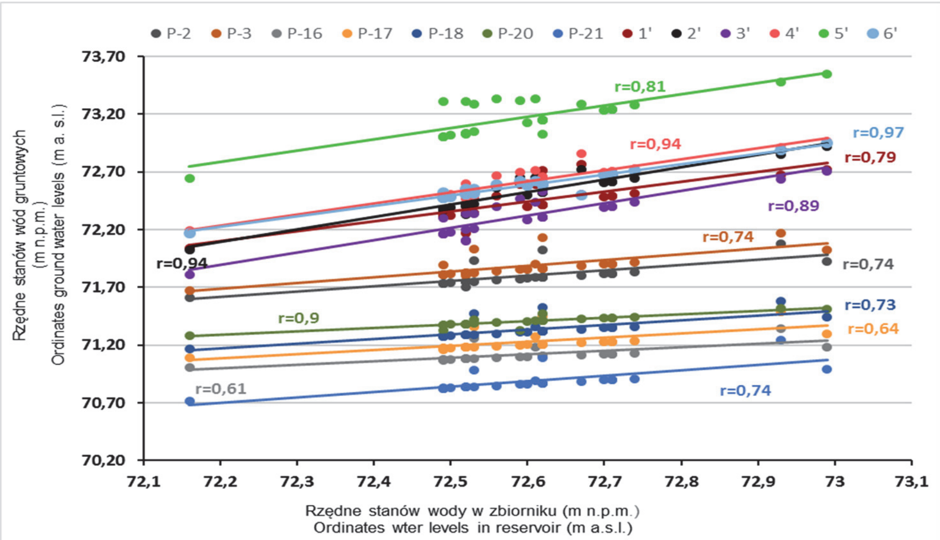

Fig. 7. Correlations between elevations of water levels in the Przebędowo reservoir and elevations of groundwater levels in analysed wells in the 2017 summer half-year

Mutual relationships between waters retained in reservoirs and groundwaters in adjacent areas have been investigated in many regions of Poland. Strong dependencies between these parameters have been stressed e.g. by Zubala (2005) and Przybyła and Kozdrój (2013) in their studies conducted on the Pakosław reservoir in the Orla river catchment. Many authors have also underlined the positive effect of waters retained in reservoirs on groundwaters in adjacent areas, manifested mainly in their supply in drought periods, as shown e.g. in studies by Szafrański and Stefanek (2008) carried out on the Mściwojów dam reservoir and by Sojka et al. (2010) in the Struga Dormowska catchment.

As it was reported by Operacz et al. (2012), an artificially raised water table by structures regulating damming height in relation e.g. to dam reservoirs considerably contributes to an increase in catchment retention. This phenomenon to a considerable extent prevents aridification of the area. According to those authors, from the point of view of water management increased underground retention, frequently close to total retention capacity of the catchment, is of paramount importance for the water cycle in the system.

For this reason it is crucial to conduct further studies on already existing facilities, which may serve as training grounds, particularly for the future new retention reservoirs and their assessed impact on the adjacent areas. According to Kanownik et al. (2011), at the accumulation of surface waters in reservoirs for their commercial or recreation use, monitoring studies are required especially in suburban areas under stronger anthropopressure. We also need to remember of the fact that the construction of dam reservoirs is considered to be particularly risky and requiring thorough analyses. Generally when assessing available water resources in catchments of watercourses located in river valleys we need to take into consideration infiltration or drainage effects of the main receiving waters on the adjacent area (Olszewska et al. 2012).

4. Conclusions

1. Conducted studies confirmed that a marked effect on the fluctuations in the water pool in the reservoir and groundwater levels in the adjacent area was exerted by the weather conditions, particularly daily precipitation totals in individual half-years of the analysed years. The maximum water levels in the reservoir and groundwaters in the analysed wells in the winter half-years was most frequently observed at the turn of March and April. In turn, in the summer half-years no definite trend was observed, as is frequently characteristic of drainless reservoirs. High water levels were most typically recorded at the turn of July and August and towards the end of those half-years.
2. Studies also showed that measures connected with water management in the flood control retention facilities, such as dam reservoirs, often significantly determine also changes in water levels both in the reservoir itself and groundwaters in the adjacent area. The measures classified as flood control prevention, e.g. opening of bottom outlets on damming structures in critical situations, contribute to the restoration or maintenance of natural outflow conditions from the catchment and limit flood damage in a given area.
3. The analysis of changes in the elevations of reservoir waters and groundwaters in the adjacent area indicated that for a greater part of the analysed hydrological years waters retained in the investigated reservoir fed groundwaters of adjacent areas, while the longest supply time, ranging from 282 days to 366 days, was found for wells P-2 to P-21 located in the vicinity of the dam. In turn, for wells from 1'to 6' located in the area of the central part of the

reservoir the flow of waters in two opposite directions was observed, with the reservoir serving draining function next to the alimentary function.

4. Calculations for the relationships between elevations of waters in the reservoir and those of groundwater levels in the investigated wells, obtained for the analysed winter and summer half-years of the studied hydrological years in most cases showed strong dependencies. However, it needs to be stressed that stronger mutual dependencies between the above-mentioned parameters were found for the summer half-years, for which calculated correlation coefficients, statistically significant at $\alpha = 0.01$, ranged from 0.61 for well P-16 to 0.99 for wells P-2 and P-3, respectively.

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Abstract

The article presents the results of investigations carried out in the hydrological years of 2015, 2016 and 2017 in the Przebędowo reservoir basin (in areas adjacent to the reservoir). It is located in the Wielkopolskie province, 25 kilometres north of Poznań in the Murowana Goślina commune. The analysed catchment with an area of approx. 100 km^2 is mostly covered by forests, while in the immediate vicinity of the reservoir it also comprises arable land. The entire catchment is covered by postglacial deposits, such as sands and clays. Areas adjacent to the reservoir are composed of quaternary (Pleistocene) fluvial deposits. The analysis of layers contained within piezometers showed the predominance of medium sands, which were deposited up to a depth of about 3 m. The groundwaters in those layers formed a continuous aquifer horizon.

The analysed reservoir was constructed in the valley of the Trojanka river, from km 6 + 915 to km 8 + 371 of the river course, by the Greater Poland Provincial Land Drainage and Water Units Board in Poznań. It was put into operation in November 2014. The earth dam of the reservoir is class IV it is 334 meters long and 3.30 meters high. The reservoir with a length of 1450 m and a maximum bed-width of 120 m at a normal damming level has a flooded surface of 12.03 ha. The main purpose of the reservoir is to store water for agricultural purposes, improve climatic and water conditions in the adjacent agricultural areas, provide protect against flooding and fire for areas lying both below the dam and adjacent to the reservoir. Around the reservoir an ecological buffer zone was made in the form of tree and shrub plantings. It reduced runoff of biogenic compounds (nitrogen and phosphorus) and pesticides from adjacent agricultural areas.

The conducted analysis of precipitation data according to the criterion developed by Kędziora (1995) (following Kaczorowska, 1962) showed that the water year of 2015 was dry. The precipitation total in that year was 429 mm and was lower than the average of the multi-year period by 131 mm, while temperature was higher than average by 0.5°C. In contrast, the water year of 2016 was wet, as the precipitation total in that year was 682 mm, i.e. by 122 mm higher than the average of the multi-year period, with the air temperature higher than the average by 0.4°C. The last water year analysed (2017) was very wet, because the precipitation total exceeded the multi-year average by 244 mm, with the air temperature close to the average.

Results indicated that next to the character of the reservoir, also meteorological conditions had a considerable impact on changes in water levels in the analysed reservoir and groundwater levels in the adjacent area. Research showed a hydraulic connection between the water retained in the reservoir and groundwater in the adjacent areas. It was found that over a greater part of the water years analysed in this paper the water retained in the Przebędowo reservoir fed groundwaters of the adjacent areas. The longest supply time, which ranged from 282 days to 366 days, was recorded for wells P-2 to P-21. They are located within a short distance from the dam. In contrast, in the case of wells 1' to 6', located near the middle part of the reservoir, two-way water flow was found. In the analysed years the water in reservoir was fed by the groundwater from the wells for a period between 7 days (st. 2') to 365 days (st. 5').

The analyses carried out in the winter and summer half-years of the discussed water years indicated mostly strong relations between the elevation of water levels in the reservoir and groundwater elevation in the studied wells. However, it was found that the interrelationships between the discussed values were stronger in the summer half-years.The obtained research results generally showed that the waters accumulated in the Przebędowo reservoir have a positive impact on groundwaters in the adjacent areas and feed them during drought periods.

Keywords:
small-scale water retention, dammed reservoirs, groundwater

Ocena oddziaływania zbiornika zaporowego na zwierciadło wód gruntowych w terenach przyległych na przykładzie obiektu Przebędowo

Streszczenie

W pracy przedstawiono wyniki badań przeprowadzonych w latach hydrologicznych 2015, 2016 oraz 2017 w zlewni zbiornika Przebędowo (w terenach bezpośrednio przyległych do zbiornika), zlokalizowanej w województwie wielkopolskim, 25 km na północ od Poznania w gminie Murowana Goślina. W omawianej zlewni, o powierzchni około 100 km^2 przeważają lasy, a w mniejszym stopniu w terenie bezpośrednio przyległym do zbiornika występują grunty orne. Na całym obszarze zalegają utwory polodowcowe takie jak piaski i gliny. W ogólnym ujęciu tereny przyległe do zbiornika zbudowane są z osadów czwartorzędowych (plejstocen) fluwialnych, a analiza warstw objętych piezometrami wykazała przewagę piasków średnich zalegających do głębokości około 3m, w których wody gruntowe tworzą ciągły poziom wodonośny. W terenie bezpośrednio przyległym do zbiornika występują grunty orne.

Analizowany zbiornik został wykonany w dolinie rzeki Trojanki, od km 6+915 do km 8+371 jej biegu przez Wielkopolski Zarząd Melioracji i Urządzeń Wodnych w Poznaniu i został oddany do eksploatacji w listopadzie 2014 roku. Ziemna zapora czołowa na zbiorniku jest klasy IV, jej długość wynosi 334 m, przy wysokości 3,30 m. Zbiornik o długości 1450m i szerokości maksymalnej 120m, przy normalnym poziomie piętrzenia (NPP) ma powierzchnię zalewu 12,03ha. Głównym celem zbiornika jest magazynowanie wody dla celów rolniczych, poprawa warunków klimatycznych i wodnych na przyległych użytkach rolnych, oraz ochrona przeciwpowodziowa i przeciwpożarowa terenów leżących poniżej zapory, a także terenów przyległych do zbiornika. Wokół zbiornika wykonano ekologiczną strefę buforową w postaci nasadzeń z drzew i krzewów, redukującą spływy związków biogennych (azot, fosfor) i środków ochrony roślin z przyległych terenów użytkowanych rolniczo.

Przeprowadzona analiza wilgotnościowa omawianych w pracy lat według kryterium Kędziory 1995 (za Kaczorowska 1962) pozwoliła stwierdzić, że pierwszy analizowany w pracy rok hydrologiczny 2015 był rokiem suchym, w którym suma opadów wyniosła 429 mm i była niższa od średniej z wielolecia o 131 mm, przy temperaturze powietrza wyższej od średniej o 0,5°C. Natomiast rok hydrologiczny 2016 był rokiem wilgotnym, w którym suma opadów wyniosła 682 mm i była wyższa od średniej z wielolecia o 122 mm, przy temperaturze powietrza wyższej od średniej o 0,4°C. Ostatni analizowany w pracy rok hydrologiczny 2017 był bardzo wilgotny, gdyż suma opadów przekroczyła w tym roku średnią z wielolecia aż o 244 mm, przy zbliżonej do średniej temperaturze powietrza.

Uzyskane wyniki badań potwierdziły, że duży wpływ na zmiany stanów wody w analizowanym zbiorniku i wód gruntowych w terenie przyległym, poza charakterem zbiornika, miał przebieg warunków meteorologicznych. Badania wykazały, że pomiędzy wodami retencjonowanymi w zbiorniku a wodami gruntowymi w terenach przyległych istnieje więź hydrauliczna. Stwierdzono, że przez większą część analizowanych w pracy lat hydrologicznych retencjonowane w omawianym zbiorniku wody zasilały wody gruntowe terenów przyległych, przy czym najdłuższy czas zasilania, wynoszący od 282 dni

do 366 dni, stwierdzono dla studzienek od P-2 do P-21 zlokalizowanych w niedalekiej odległości od zapory. Natomiast w przypadku studzienek od 1'do 6' zlokalizowanych w okolicach środkowej części zbiornika stwierdzono dwukierunkowy przepływ wód. W analizowanych latach wody gruntowe zasilały od strony tych studzienek wody zbiornika przez okres od 7 dni (st. 2') do 365 dni (st. 5').

Przeprowadzone w analizowanych półroczach zimowych i letnich omawianych lat hydrologicznych obliczenia związków pomiędzy rzędnymi stanów wody w zbiorniku, a rzędnymi zwierciadła wód gruntowych w badanych studzienkach wykazały w większości silne zależności. Stwierdzono jednak, że wzajemne powiązania pomiędzy omawianymi wielkościami silniejsze były w półroczach letnich analizowanych lat.

W ogólnym ujęciu uzyskane wyniki badań wykazały, że zasoby wodne gromadzone w zbiorniku Przebędowo pozytywnie oddziaływają na wody gruntowe terenów przyległych, zasilając je w okresach posusznych.

Słowa kluczowe:
mała retencja, zbiorniki zaporowe, wody gruntowe