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Changes in Groundwater Levels in the Catchment of the Jeżewo Retention Reservoir

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1. Introduction

Water scarcity is an increasingly severe problem worldwide [8]. Presently observed and forecasted climate changes indicate that over the coming decades Europe is likely to suffer more frequent meteorological droughts [1]. Mediterranean islands of Cyprus and Malta and some of densely populated central EU-25 Member States including Germany, Italy, Poland, Spain and southern United Kingdom have the least available water per capita. In Poland regions with particularly low water resources include e.g. the catchment of the Warta River, belonging to the Odra river basin, and especially its central part [3, 11]. In order to improve the availability of water resources in Poland, especially for the needs of agriculture, in 1995 regional development programmes were prepared for the development of small-scale retention. They were updated with the introduction of a new administrative division in 1999. At that time 16 regional development programmes were prepared for small-scale retention. These programmes took into consideration mainly engineering methods of water retention, such as e.g. small water reservoirs (up to 5 million m^3), damming of lakes and channel retention. In the years 1998–2005 the mean annual increment in stored water of slightly over 14 million m^3 was recorded in Poland, which is only 23% of the plan contained in the programmes for small-scale retention in Poland by 2015, amounting to 60 million m^3 [7]. In the analyzed period the highest increase in retention was recorded in the Wielkopolska province, located mostly in the catchment of the Warta, while the increment of retained water resulted mainly from the construction of man-made water reservoirs (61%) [11]. Realisation of these investment projects has changed considerably water relations in the catchment. Since such investment projects are classified as investments with a high potential environmental impact, it is necessary to conduct studies which would determine the impact of the water reservoir on adjacent areas, including fluctuations of ground water tables. One of such water reservoirs is the Jeżewo water reservoir analysed in this study.

The aim of the paper is to evaluate fluctuations and changes in the depth of ground water tables in the catchment of the Pogona in the years 2002–2008 and to present an attempt at the evaluation of the range of impact of water levels in the reservoir on ground water tables in adjacent areas.

2. Methods

Studies were conducted in an area adjacent to the water reservoir Jeżewo, located in the valley of the Pogona River at the section from 4+420 to 6+628 km, administratively belonging to the Borek Wielkopolski commune, the Gostyn county, the Wielkopolskie province [12].

It is a lowland water reservoir, of the valley type with a shape resembling the reversed letter S. The water reservoir is 2.2 km in length, and its area is 75.35 ha. In terms of its geomorphology the catchment is formed by the undulating bottom moraine plain of the Vistula glaciation, the Leszno period. The Pogona together with the water reservoir forms a left-bank tributary of the Kościan Obra Canal, at 82+900 km of its course. The total area of the catchment of the Pogona is 134 km^2, while at the dam cross-section it is 129 km^2. Mean flow from the multi-year period at the Jeżewo section line is 0.391 m^3/s, while the minimum admissible flow is 0.050 m^3/s. Maximum damming altitude of the water reservoir was established in the design documentation at 101.10 m a.s.l., while the minimum – at 98.00 m a.s.l., maximum capacity is 2.10 million m^3, while operating capacity is 1.43 million m^3. Damming height at the dam is 7.7 m, while the mean flooded depth at the total capacity of the water reservoir is 2.3 m. Maximum flooded area of the water reservoir is 90.0 ha, and the minimum area is 20.0 ha.

Analyses were conducted in 11 control wells located around the water reservoir at a distance from 100 to 1100 m (Fig. 1). Measurements were taken every month from February 2002 to March 2008 (both before and after the filling of the reservoir in March 2004). The water table contour system for ground water tables is shown in Figure 2.

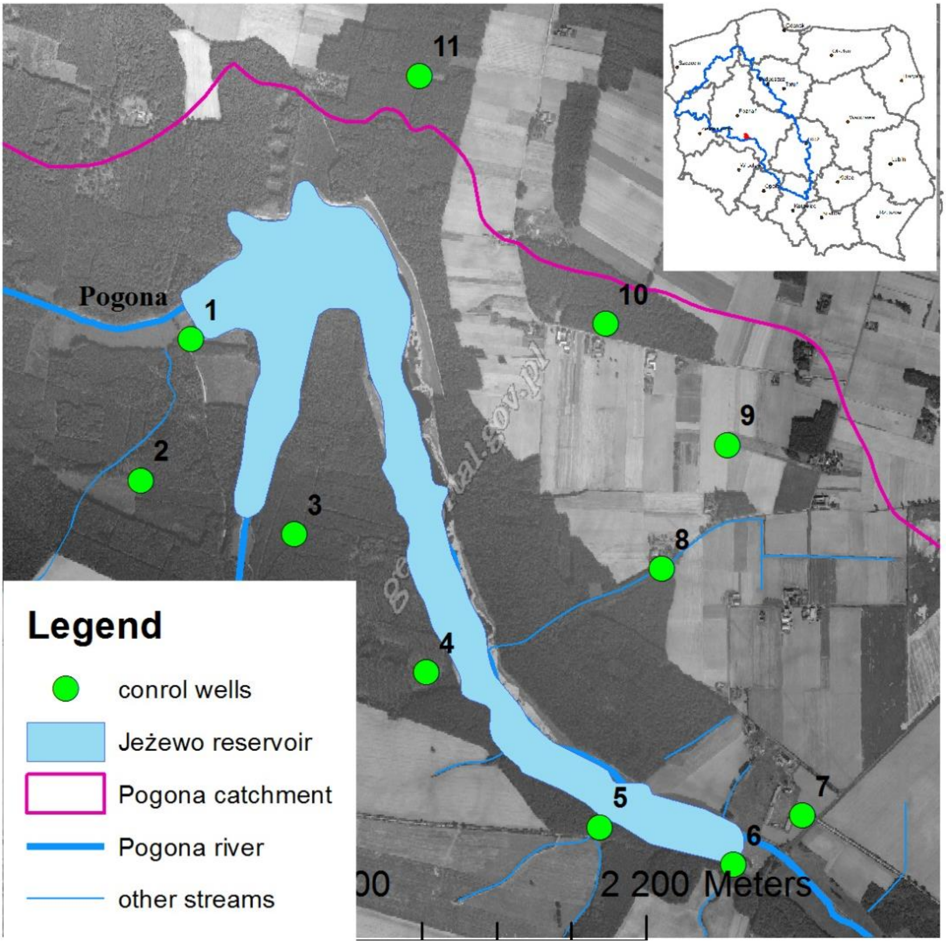

Fig. 1. Distribution of control wells around the Jeżewo reservoir
Rys. 1. Rozmieszczenie studzienek kontrolnych wokół zbiornika Jeżewo

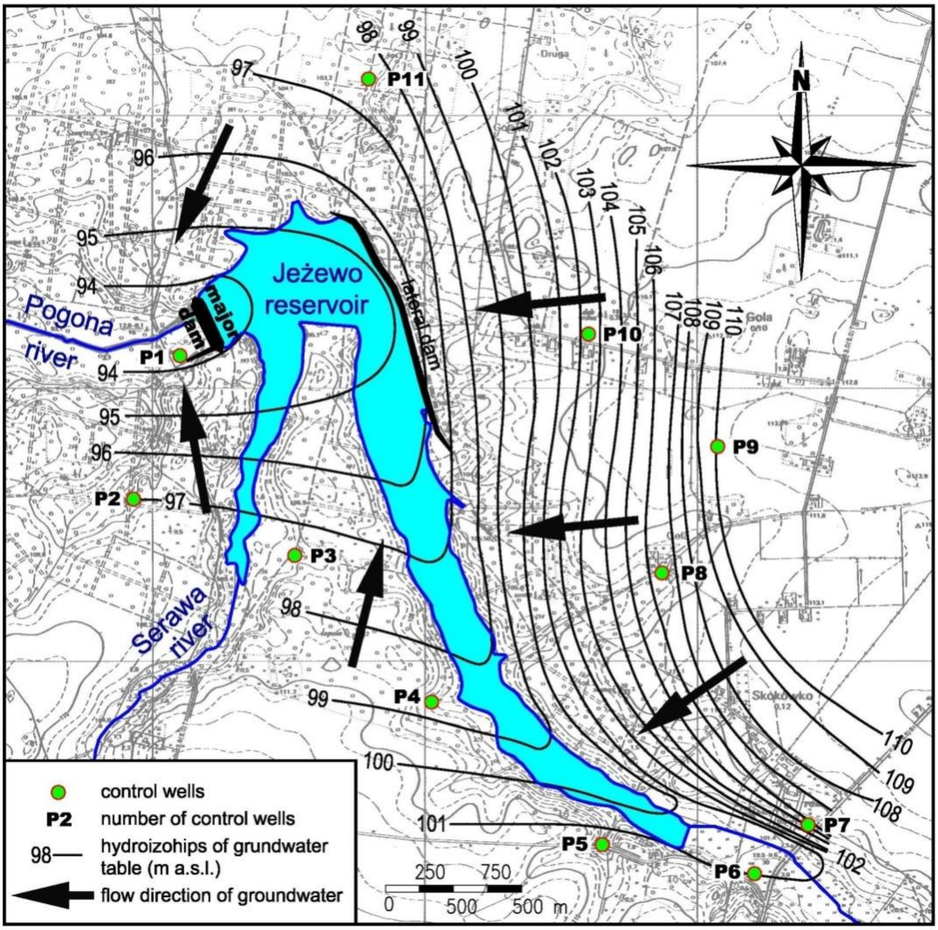

Fig. 2. Hydroizohips of groundwaters table in an area adjacent to the water reservoir Jeżewo (m.a.s.l.)

Rys. 2. Hydroizohipsy zwierciadła wód gruntowych w rejonie zbiornika Jeżewo (m n. p. m.)

3. Results and Discussion of Results

The analysed area has to be classified as an area with considerable water deficits. This is manifested both in the low annual precipitation totals and low water retaining capacity of the catchment, characterised by low values of unit flow and at the same time high evapotranspiration. The mean value of unit runoff is 4.4 $dm^3/s \cdot km^2$, while for the extreme values it is 26.5 and 0.15 $dm^3/s \cdot km^2$. Low values of runoff result from deficit of precipitation and from the low water retaining capacity of this area. The high value of flow irregularity rate, measured by the ratio of maximum flow to minimum flow, is 173 and confirms this conclusion. Typically the levels and flows higher than mean annual values are observe din the period from January to the end of April.

In the analysed area ground waters were characterised generally by free water tables. Only in one case (P09) thrust conditions were identified. The water table drilled at a depth of 8.80 m below ground level settled at a level of over 6 m higher.

The direct impact on the ground water table in individual control wells is found for the water level in the reservoir. During the conducted investigations the course of changes in ground water tables varied in the analysed control wells.

Figure 4 presents altitudes of ground water tables in the group of deep control wells (above 400 cm below ground level) in relation to the water level in the reservoir. The altitude of the water in well 10 exceeds the altitude of water level in the reservoir. The water reservoir in this case does not have any impact on the level of ground water in that well. A similar dependence was found in wells nos. 7, 8 and 9, which are located 250, 600 and 1100 m, respectively, from the reservoir dam (Fig. 3). The situation is different in case of the other wells. Control well P1, situated in a close vicinity of the water reservoir (150 m), does not react to the water level in the water reservoir. This probably is caused by the fact that the cofferdam is located in the front dam. The other control wells respond to the level of water in the reservoir. In all shallow control wells (from 0 to 400 cm below ground level) (Fig. 3) the water level changed cyclically both before filling and after the filling of the water reservoir. A decrease was observed in the ground water level connected with the vegetation period, in which water uptake by plants increases considerably. These cyclical changes were connected mainly with the relation between precipitation and evapotranspiration, which in the summer period at a shortage of precipitation in relation to evapotranspiration leads to soil overdrying and lowering of the ground water table, while in the autumn-winter period, when precipitation exceeds evapotranspiration – to the restoration of water retaining capacity of soil and ground water tables [2, 4, 5, 6, 13]. This dependence was most evident in well P9. In winter semester when underground water resources are replenished, we observe a seasonal increase of ground water tables.

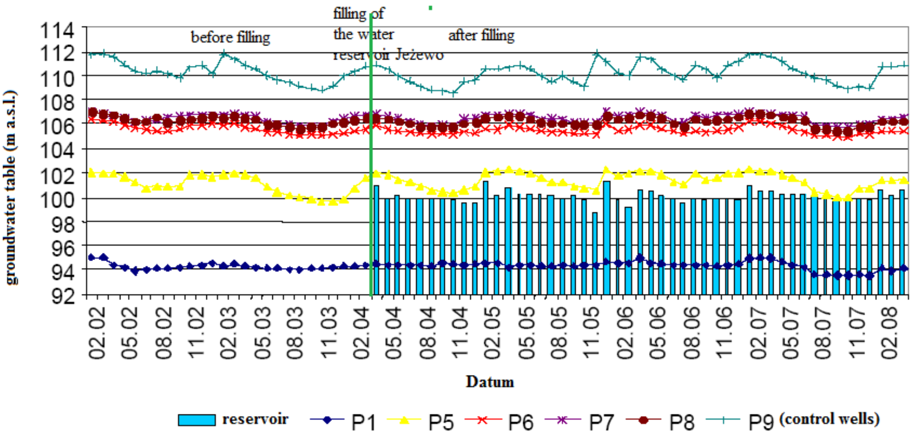

Fig. 3. The course of changes in ground water tables in shallow wells and the damming water level in the Jeżewo reservoir
Rys. 3. Przebieg zmian zwierciadła wód gruntowych studzienek płytkich oraz poziomu piętrzenia wody w zbiorniku Jeżewo

Differences in the depth of ground water tables in different control wells may be as high as several metres, which is connected with the layout of land as well as its geological structure. In deep control wells (Fig. 4) after the reservoir had been filled in 2004, an increase was observed in the level of ground waters. The greatest increase in the ground water levels was recorded in case of control well P4.

After analysis of the 7-year period it may be stated that the ground water levels in the zone of the potential impact of the Jeżewo reservoir were highly varied. Mean amplitude of ground water levels in the examined period was 2.07 m, the smallest fluctuation in ground water tables was recorded in well P10 – 0.90 m, while the greatest in P9 – 3.32 m.

In shallow control wells the level of water tables in the entire period ranged from 113 to 291 cm below ground level (Fig. 3). Except for control well P1, the ground water tables in all the gauging points did not exceed the altitude of water in the reservoir. Despite the fact that control well P1 is located in the close vicinity of the reservoir, the impact of water damming in the reservoir on the ground water level in this well was not observed. This could have been caused by the fact that a cofferdam of metal sheet piles is located in the front dam, which was formed in order to cross the filtration route.

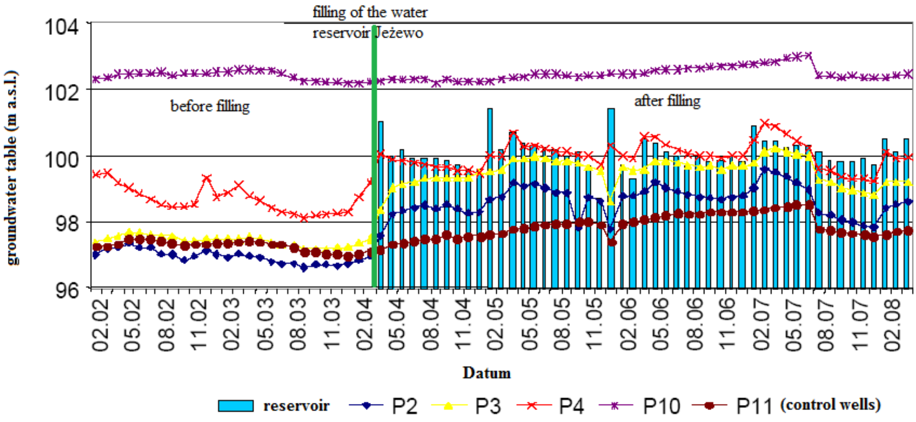

Fig. 4. The course of changes in ground water tables in deep wells and the damming water levels in the Jeżewo reservoir
Rys. 4. Przebieg zmian zwierciadła wód gruntowych studzienek głębokich oraz poziomu piętrzenia wody w zbiorniku Jeżewo

In deep control wells the mean depth of water table exceeds 500 cm below ground level. In all control wells of that group, except for control well P10, ground water tables were located below the water level in the reservoir. In the first year after the reservoir had been filled a marked increase in ground water levels was recorded in control wells P2, P3 and P4, amounting to 1.50 up to 1.78 m. Mean depth of ground water tables in control wells in the years 2002–2008 ranged from 1.13 to 7.97 m (Table 1). Minimum depth of ground water levels was recorded in well P8, amounting to 0.44 m, while the maximum was found in well P4 – 9.37 m.

A permanent increase in the mean ground water table was recorded in control wells P2, P3, P4 and P11. In these control wells the water table was close to the altitude of the water level in the reservoir, and occasionally it was even identical (control wells P3 and P04). It had serious hydrogeological consequences. This reflects the two directions of the water stream flow in the aquifer. Periodically infiltration of water from the reservoir to the aquifer was possible (alimentation), while in other periods drainage predominated. This also reflected the variation in the range of impact of the water reservoir on ground waters in the first aquifer.

Table 1. Water levels in control wells
Tabela 1. Charakterystyka poziomu wód gruntowych w studzienkach

Control well no.	Type of control well	Depth of control well (m)	Distance of control well from reservoir	Altitude of area (m a.s.l.)	Water levels in the study period 2002–2008 (m)		
					min.	mean	max
P8	shallow	3.9	400	107.44	0.44	1.21	4.86
P6	shallow	5.0	200	102.75	1.08	1.87	2.53
P5	shallow	5.6	200	104.14	1.89	2.91	3.98
P7	shallow	7.4	150	107.62	0.55	1.13	1.9
P9	shallow	9.9	600	112.69	0.91	2.49	4.37
P3	deep	6.6	150	103.74	3.53	4.99	6.58
P2	deep	6.7	150	103.27	3.72	5.28	6.63
P4	deep	7.7	150	107.47	6.53	7.97	9.37
P11	deep	8.0	1100	102.84	4.68	5.20	5.96

Significant conclusions were also supplied by the analysis of changes in water levels in well P11, in which a permanent increase in the mean depth of the water table was observed, although it was much lower than in control wells P2, P3 and P4. The case of the discussed control well is of interest for at least two reasons. First of all it was located in the zone of the watershed, in the area of the interfluve of the Kościan Obra Canal and the Pogona. Due to the geological structure, including lithology, it is a good indicator of the direction of water flow in the aquifer. This makes it possible to state instability of the subsurface location of the watershed and it is significant, since it facilitates alimentation of ground waters in the valley of the Kościan Obra Canal by the reservoir.

On the other hand, control well P11 was the only control well, which after the construction of the dam on the Pogona was characterised by an almost continuous increase in the altitude of the water table. This trend was effectively disrupted only once – at the beginning of hydrological year 2006 (Fig. 4), when as a result of the breakdown of the side dam damming in the reservoir was reduced.

4. Conclusions

A comparison of dynamics of changes in ground waters with damming levels in the water reservoir in the years 2002–2008 indicated two significant directions in the functioning of the small-scale retention reservoir – water retaining capacity in the bankful flow periods and feeding of low water flows in periods of water shortages.

On the basis of analyses it may be stated that the ground water tables in the zone of potential impact of the Jeżewo reservoir were highly varied. Mean amplitude of ground water levels in the investigated period was 2.07 m, the smallest changes in the ground water levels were recorded in well P10 at 0.90 m, while the greatest in P9 at 3.32 m. The greatest impact of water damming in the reservoir on ground water tables was observed in deep control wells nos. 2, 3 and 4, which are located in areas composed of permeable sandy layers, creating good conditions for the infiltration of water from the reservoir, and at a distance of 150 m from their reservoir bank. This effect was not found in the shallow control wells nos. 7, 8 and 9, located in areas composed mainly of sandy clays and loamy sands, at a distance of 150, 400 and 600 m, respectively, from the reservoir bank.

Dynamics of changes in the ground water levels in the investigated area was determined mainly by weather conditions, i.e. precipitation and air temperature. The other physical and geographical conditions could have a modifying effect. Dynamics of changes in ground water levels showed a greater variability in agriculturally utilized areas than in forest areas.

A considerable modifying role was also attributed to the valley of the Pogona River, particularly its gap section (the bowl of the Jeżewo reservoir). The original valley mouth of the Pogona paleovalley, directed north towards the Kościan Obra Canal (The Żerków-Rydzyna Paleovalley), was filled by deposits of the sandy fractions (medium-grained and fine sands). As a result of water damming in the Jeżewo reservoir a change occurred towards infiltration within the interfluve of the Kościan Obra Canal and the Pogona. The predominant direction of the infiltration "to the water reservoir" is reversible – the drainage of the Pogona river system by the Kościan Obra Canal takes place. In the immediate vicinity of the reservoir a change takes place in the filtration zone, particularly an initial reduction of the hydraulic gradient, an increase in underground water retention, i.e. hindered runoff and finally the reconstruction of the subsurface system of the watershed. A shift is observed in the underground watershed and a change in the direction of infiltration. In case of the Pogona catchment the described situation took place in the interfluve of the Kościan Obra Canal and the Pogona. At the stable topographic divide and a changing underground watershed the Kościan Obra Canal was fed by precipitation waters caught in the area of the Pogona catchment. The impact of the front dam of the reservoir was found, which significantly reduced the exchange of water in the aquifer between control well P1 and the reservoir. It also needs to be remembered that the perched water table observed in well P9 turned out to be a single factor disturbing the flow of ground waters between the reservoir in Jeżewo and the aquifer. The greatest impact was exhibited for ground waters observed in the control wells located either in the vicinity of the existing river valleys, particularly the Pogona and the Serawa, or in the area of the paleovalley (erosion slit) of the Pogona. In those areas the altitude of ground water tables reached lower values or at times it was identical to the damming levels in the reservoir above the sea level. As a result, the gravitational transfer of watery occurred in the aquifer. Thus both alimentation of the reservoir and its drainage took place.

The front dam is also of significant importance. It is evident that in the control wells established below the damming facility no changes were observed in the altitude of the ground water table of the first aquifer, which could have been connected with the water regime of the reservoir. This indicates a considerable tightness of the structure. In this case the general direction of infiltration of ground waters was disturbed by the anthropogenic impact.

Water in the Jeżewo reservoir did not change the main direction of water infiltration in the aquifer – still runoff predominated with the main north-western and northern components (in places western) being consistent with the course of the main geological structure, i.e. a subglacial channel, and the drainage role was still served by the Kościan Obra Canal. The construction of the water reservoir contributed to the local and periodical changes in the direction of water infiltration in the aquifer, which pertained particularly to the area of wells P2, P3, P4 and P11. Depending on the level of water damming in the reservoir, drainage or alimentation of the aquifer occurred between the reservoir and control wells.

Control wells indicating symptoms of the impact of the reservoir reacted in different ways, depending on the relation of the altitude of the ground water table to the altitude (a.s.l.) of the water level in the Jeżewo reservoir before damming. Thus the greatest, permanent change in the depth of water was found in control wells P2, P3, P4 and P11, while it was periodical in control wells P05, P06 and P10. A lack of impact of the water reservoir was observed in control wells P07, P08, P09 and P01.

When analysing altitudes of water damming in the reservoir and the water level of ground waters in control wells P04, P05 and P06 it may be stated that infiltration in their vicinity was two-directional, since the water reservoir alternately alimented and drained the aquifer. A similar dependence was found in the interfluve of the Pogona and the Kościan Obra Canal, while it was confirmed by the systematic increase in the water table in well P11.

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Zmiany zwierciadła wód gruntowych w zlewni zbiornika retencyjnego Jeżewo

Streszczenie

Polska, a zwłaszcza jej środkowa część, w tym Wielkopolska należą w skali kontynentu europejskiego do ubogich w zasoby wodne regionów. Jednym ze sposobów poprawy tego stanu jest realizacja małych zbiorników wodnych, które znacząco zmieniają stosunki wodne w danej zlewni.

W pracy przedstawiono wyniki badań głębokości zalegania zwierciadła wód gruntowych prowadzonych w latach 2002–2008 na obszarze przyległym do zbiornika Jeżewo. Analiza opierała się na pomiarach prowadzonych na 11 piezometrach położonych w bezpośredniej zlewni zbiornika. Pomiary wykonywano początkowo raz w miesiącu, a od 2008 r. – co tydzień.

Na podstawie przeprowadzonych badań można stwierdzić, że zwierciadło wód gruntowych w strefie potencjalnego wpływu zbiornika Jeżewo układało się w sposób bardzo zróżnicowany. Średnia amplituda stanów wód gruntowych w badanym okresie wyniosła 2,07 m, najmniejsze zmiany stanów wód gruntowych zanotowano w studzience P10 – 0,90 m, największe zaś w P9 –

3,32 m. Największy wpływ piętrzenia wody w zbiorniku na zwierciadło wód podziemnych obserwowano w studzienkach głębokich: nr 2, 3 i 4, które są zlokalizowane na terenach zbudowanych z dobrze przepuszczalnych warstw piaszczystych, tworzących dobre warunki filtracji wód ze zbiornika, i oddalone od linii brzegowej zbiornika o 150 m. Wpływu tego nie wykazały studzienki płytkie: nr 7, 8 i 9, zlokalizowane na terenach zbudowanych głównie z glin piaszczystych i piasków gliniastych, oddalone o – odpowiednio – 150, 400 i 600 m od linii brzegowej zbiornika.

Bezpośredni wpływ na poziom zwierciadła wody gruntowej w poszczególnych studzienkach kontrolnych miał poziom zwierciadła wody w zbiorniku. Na podstawie badań stwierdzono, że zwierciadło wód gruntowych w strefie potencjalnego wpływu zbiornika Jeżewo układało się w sposób zróżnicowany. W studzienkach kontrolnych płytkich poziom wód zmieniał się w sposób cykliczny zarówno przed, jak i po napełnieniu zbiornika. Obserwowane obniżenie poziomu wód gruntowych było związane z okresem wegetacyjnym, w którym pobór wody przez rośliny znacznie wzrasta. Cykliczność była związana głównie z relacją pomiędzy opadem a ewapotranspiracją, która w okresie letnim przy niedoborze opadów w stosunku do parowania terenowego prowadzi do przesychania gleb i obniżenia zwierciadła wód gruntowych, natomiast w okresie jesienno-wiosennym, kiedy opady przewyższają ewapotranspirację, obserwowano odbudowę retencji glebowej oraz podnoszenie się zwierciadła wód gruntowych.