DOI: 10.2478/jwld-2014-0014

JOURNAL OF WATER AND LAND DEVELOPMENT
J. Water Land Dev. 2014, No. 21 (IV–VI): 55–62
PL ISSN 1429–7426

Available (PDF): www.itep.edu.pl/wydawnictwo; http://www.degruyter.com/view/j/jwld

Received 20.11.2013
Reviewed 23.01.2014
Accepted 07.03.2014
A – study design
B – data collection
C – statistical analysis
D – data interpretation
E – manuscript preparation
F – literature search

Seasonal variability of ground water levels in the Puszcza Zielonka Forest

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For citation: Grajewski S., Miler A.T., Okoński B. 2014. Seasonal variability of ground water levels in the Puszcza Zielonka Forest. Journal of Water and Land Development. No. 21 p. 55–62

Abstract

The paper presents results of studies on seasonal variability of ground water tables recorded in long-term observations of water levels in the Puszcza Zielonka forest complex. The Puszcza Zielonka Forest is located in the middle part of the Warta basin in the central part of the Wielkopolska region. Its western boundary is located approx. 6 km north-east of Poznań. The area is situated in the western part of the Wielkopolska-Mazovian climatic region. The natural landscape is of young glacial type of Pleistocene and Holocene formation. For this reason parent materials for soils in this area were mainly postglacial drifts, deposits coming from the Poznań stage of the Würm glaciation. In terms of granulometric composition these were mainly low clayey sands deposited on loose sands with an admixture of gravel and eroded sandy clay. Scots pine is the dominant species. Oaks, alders, larches and scarce spruces are also found in this area. Predominant sites include fresh mixed forest, fresh mixed coniferous forest, fresh broadleaved forest and alder swamp forest.

Seasonal variability in groundwater levels depends mainly on abiotic factors. Characteristics of stands have only a modifying effect on the dynamics of changes in groundwaters. Slightly greater fluctuations in water levels were recorded in the fresh broadleaved forest site in comparison to the alder swamp forest. There are no marked dependencies of fluctuations in groundwater tables on age classes of the tree stands. Generally a negative correlation was found between variability in groundwater levels and the depth of its table below ground surface (b.g.s.). However, in the conducted studies the hypothesis on the marked delay in the variability of groundwater levels between sites, tree species, age of tree stands or depth of ground water tables was not confirmed.

Key words: *groundwaters in forests, seasonal variability in groundwater levels, the Puszcza Zielonka Forest*

INTRODUCTION

Seasonal fluctuations are observed for many hydrometeorological characteristics. Annual variation in the position of groundwater table are determined by the seasonal variability in recharge of aquifers and potential of their drainage by watercourses regulated in the microscale by the operation of hydraulic engineering structures [KOWALCZYK *et al.* 2012]. In the case of forested areas short-term changes are a reaction to weather conditions and depend on the transpiration of the stand and evaporation [KROGULEC *et al.* 2011; LIBERACKI, SZAFRAŃSKI 2013; PIERZGALSKI 2008; STASIK *et al.* 2011; SULIŃSKI 1989; SULIŃSKI, JAWORSKI 1998; TYSZKA 1995]. In turn, long-term changes, apart from climatic conditions, depends also on biometric characteristics of the stand changing in its successive development stages [SULIŃSKI, KUCZA 1987]. TYSZKA and STOLAREK [2003] stated that the volume of recharge of soil water resources depends on the rate of transformation of precipitation by tree crowns and stems and on the potential for water absorption by the ground. Disturbances in this process in the winter months are caused by frost penetration of soils and snow retention.

In June and July a considerable increase in precipitation and heavy rainfall promote replenishing of groundwater resources. In August and September the limited volume of resources is determined by the level of rainfall in that period and outflows. MILER *et al.* [2003] recorded the greatest fluctuations in groundwater levels in alder swamp forest sites, where waters were deposited the nearest to the ground surface. A study by TYSZKA and STOLAREK [2003] showed the effect of not only site moisture content, but rather its fertility, species composition of the stands and their age on the level of water consumption. Long-term changes in groundwater levels many be connected both with adverse climatic changes [ECKHARDT, ULBRICH 2003; PIERZGALSKI *et al.* 2002], and with changes in forest management, e.g. stand transformation [SULIŃSKI 1981]. Generally speaking, there is a negative correlation between variation in groundwater levels and depth of its table. In turn, the character of variability in groundwater levels in a given site depends not only on the site itself, but rather the depth of groundwater deposition [MILER *et al.* 2003; MILER, PRZYBYŁA 1997].

To date when describing annual variation in groundwater levels the following measures were applied: standard deviation of multiannual means of monthly depths [PASZCZYK 1973; PIETRYGOWA 1989], the mean of standard deviations of monthly depths [CHEŁMICKI 1991], an amplitude of multiannual means of the underground water table [CHEŁMICKI 1991] and Markham's index [TOMALSKI 2010]. Periodograms were also analysed in order to detect the annual rhythm of changes in the position of the water table in aquifer horizons [BUCZYŃSKI *et al.* 2005; YAKIMOVA 2005].

The aim of this study was to determine seasonal changes in water levels in the first aquifer horizon in the Puszcza Zielonka Forest based on results of observations conducted in the hydrological years 2001–2009.

STUDY AREA AND METHODS

The Puszcza Zielonka is a compact forested area of ~15 thousand ha located in the central part of the Wielkopolska region. The western boundary of the Puszcza Zielonka Forest is located approx. 6 km north-east of Poznań (Fig. 1). This area is situated in the western part of the Wielkopolska-Mazovian climatic region. The natural landscape was created during the last glaciation, i.e. the Poznań stage of the Würm glaciation. The granulometric composition comprises mainly low clayey sands deposited on loose sands with an admixture of gravel and eroded sandy clay.

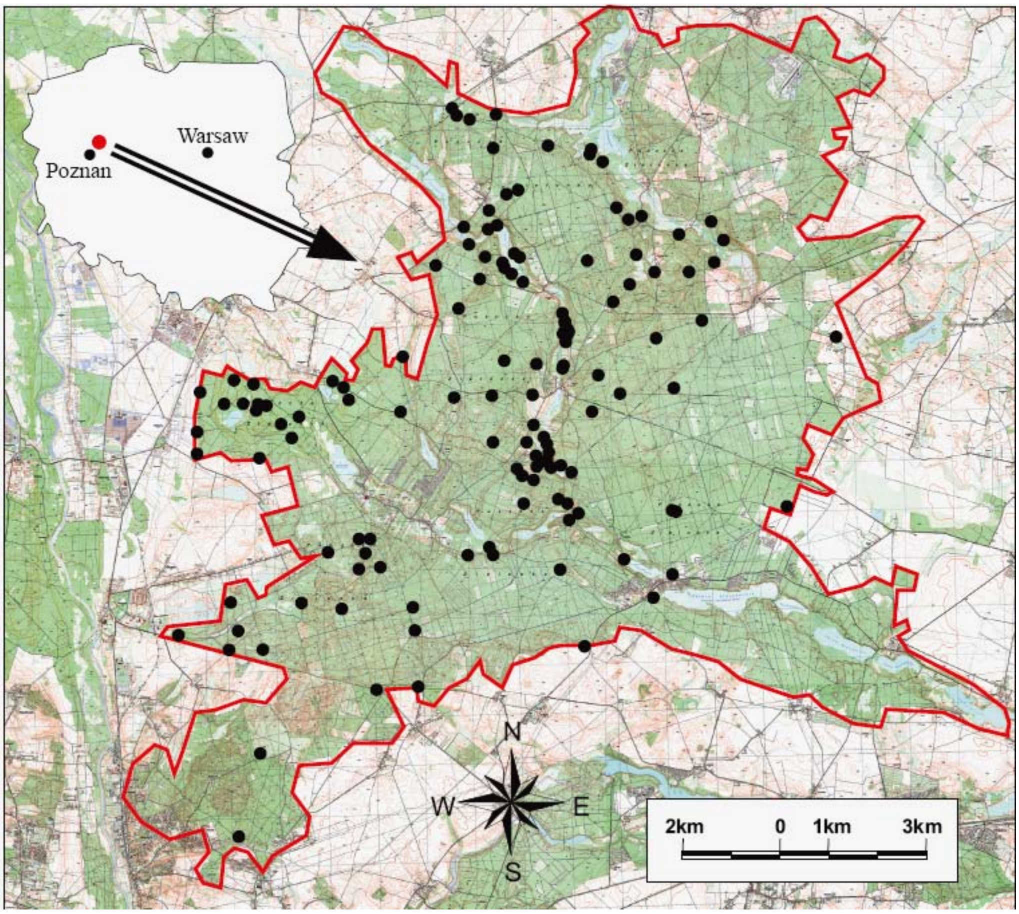

Fig. 1. Puszcza Zielonka Forest location and arrangement of groundwater measuring wells (●)

Scots pine *Pinus sylvestris* L. is the main forest-forming species at ~72%. Other species found in that area include English oak *Quercus robur* L., sessile oak *Q. petraea* (Matt.) Liebl. accounting jointly for ~15%, common birch *Betula pendula* Roth. at ~4%, black alder *Alnus glutinosa* Gaertn. at ~3%, larch *Larix ssp*. at ~2%, Norway spruce *Picea abies* (L). Karst. at ~1%, and European beech *Fagus sylvatica* L. at ~1%. The most frequently found forest site type is fresh mixed forest (LMśw) accounting for ~58%, fresh mixed coniferous forest (BMśw) at ~25%, fresh broadleaved forest (Lśw) at ~10% as well as typical alder swamp forest (Ol) and ash-alder swamp forest (OlJ), jointly comprising ~4%.

The Puszcza Zielonka Forest is located in the western part of the Wielkopolskie Lake District in the middle section of the Warta basin. Water from the Puszcza Zielonka Forest is discharged directly by the Warta River and through its tributaries: the Dzwonówka (Kanał Dzwonowski), the Trojanka (Goślińska Struga), the Główna, the Mała Wełna, the Goślinka and the Owińska Struga, as well as other small tributaries of the Warta forming 3rd, 4th and 5th order catchments [GRAJEWSKI 2006]. A considerable part of the Puszcza Zielonka is covered by endorheic areas, of which the largest extends from Głębocko to as far as Dziewicza Góra.

In the years 2001–2002 a total of 132 groundwater measuring wells were installed in the Puszcza Zielonka, with their locations selected so that (Fig. 1) they represented basic forest site types in the Forest, the main forest-forming species found in that area as well as the predominant age of the stands. Detailed data on the wells were presented in studies by GRAJEWSKI [2004; 2006] and OKOŃSKI [2006]. Standard measurements of groundwater levels were conducted in the years 2001–2004, while in selected 50 locations they were continued up to the year 2009.

For the purpose of this study mean levels were calculated from weekly recorded groundwater levels, combining them in groups in terms of forest site types, the dominant species in the stand, the age of the stand and the depth of the water table. The division of wells into shallow with the mean annual groundwater level within the range of 0÷100 cm below ground surface (b.g.s.), medium (101÷200) and deep (>200) was adopted arbitrarily, according to the range of variability in the observed groundwater levels.

RESULTS

Mean monthly depth of groundwater table in all wells ranged from 0.02 to 9.48 m, at monthly amplitudes ranging from 0.31 to 3.24 m. The course of averaged fluctuations in groundwater levels is comparable to the continental type with the maximum in April, regression until September and a gradual rise starting from October (Fig. 2). The greatest scatter of results was observed in March and April, i.e. months of maximum water retention in the saturation zone of the soil profile. Equally marked discrepancies were also found for the other months of the winter hydrological half-year as well as May. Basic statistics for groundwater levels in all wells are given in Table 1.

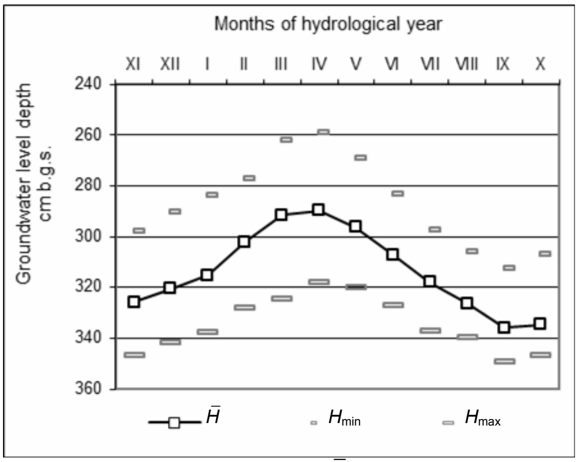

Fig. 2. Minimum H_{min}, mean $\bar{H}$ and maximum H_{max} monthly groundwater levels; source: own study

Table 1. Selected statistics for monthly groundwater levels of all groundwater wells

Mean groundwater level, cm						Mean amplitude, cm			Standard deviation	Coefficient of variation
annual			half-years		growing season	annual	winter half-year	summer half-year		
mean	min	max	winter	summer						
314	287	335	307	320	312	48	55	41	17.85	0.06

Source: own study.

In the analysed period on average groundwaters were pitched the shallowest in alder swamp forest sites, i.e. at 103 cm b.g.s., while they were lying the deepest in fresh coniferous forest sites – at 483 cm b.g.s. (Tab. 2). Analysis of mean monthly levels for wells grouped according to forest site types showed great similarity in its course, with the greatest correlation observed for wells in the fresh mixed forest and fresh mixed coniferous forest sites (r = 0.999), whereas it was lowest, although still high, for wells in the fresh broadleaved forest and alder/ash-alder swamp forest sites (r = 0.913) – Fig. 3. On average groundwater tables were found the deepest in the fresh coniferous forest site, while the greatest scatter of results were observed for gauging points located in the fresh broadleaved forest sites (Tab. 2). The culmination point for all sites was recorded in April, while maximum recession was observed in September and October, except for alder/ash-alder swamp forest (September) and fresh mixed coniferous forest (October).

Table 2. Selected basic statistics for the monthly groundwater levels by forest site types

Forest site type	Mean ground water level, cm						Mean amplitude, cm			Standard deviation	Coefficient of variation
	annual			half-years		growing season	annual	winter half-year	summer half-year		
	mean	min	max	winter	summer						
Ol/OlJ	103	82	125	89	118	107	43	48	39	14.47	0.15
Lśw	428	381	465	423	433	423	83	90	76	32.47	0.08
LMśw	300	280	317	296	305	298	37	40	34	13.23	0.04
Bśw	483	460	500	479	487	482	40	43	38	15.87	0.03
BMśw	325	295	348	320	330	323	54	63	45	20.37	0.06

Explanations: Ol/OlJ – alder/ash-alder swamp forest, Lśw – fresh broadleaved forest, LMśw – fresh mixed forest, Bśw – fresh coniferous forest, BMśw – fresh mixed coniferous forest.
Source: own study.

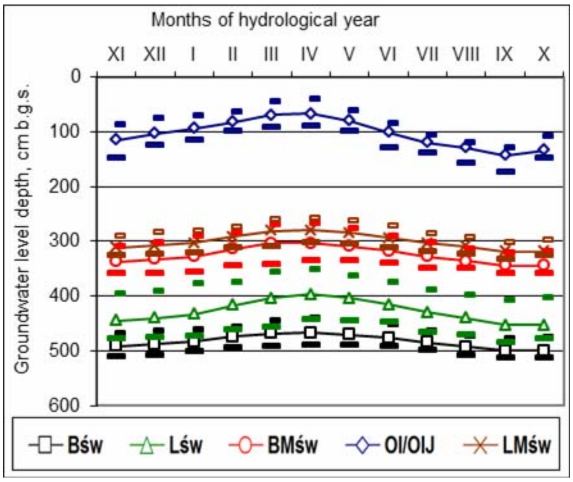

Fig. 3. Minimum (-), mean (Bśw, Lśw, BMśw, Ol/OlJ, LMśw) and maximum (–) monthly groundwater levels; Bśw – fresh coniferous forest, Lśw – fresh broadleaved forest, BMśw – fresh mixed coniferous forest, Ol/OlJ – alder/ash-alder swamp forest, LMśw – fresh mixed forest; source: own study

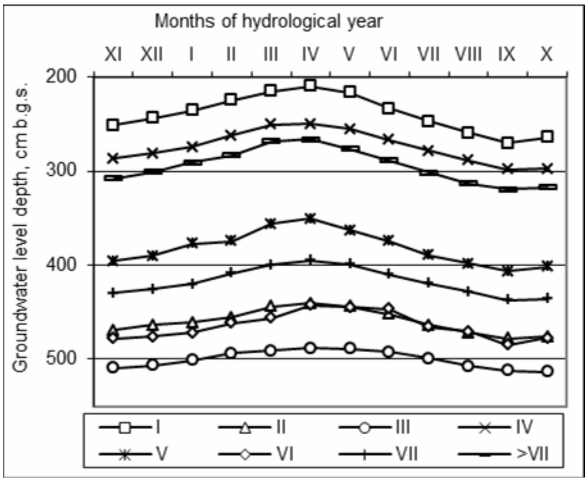

Fig. 4. Mean monthly groundwater levels by tree stand age classes: I – 1–20, II – 21–40, III – 41–60, IV – 61–80, V – 81–100, VI – 101–120, VII – 121–140, >VII – >140 years old; source: own study

In the prepared graphs of mean monthly groundwater levels in age classes of the stands significant differences in the course of curves may hardly be observed, which is confirmed by high values of calculated liner correlation coefficient $r > 0.965$ (Fig. 4). The water table in stands of age class 1 exhibits the greatest variability and scatter of results (Tab. 3). This phenomenon may be explained both by its shallow depth and by the fact that in this age class (1–20 years) plots are grouped starting from young plantations to closed sampling stands. The above mentioned stand development phases are characterised by completely different water requirements (transpiration) and the level of interception, which is crucial for the fluctuations in water relations in these plots.

Table 3. Selected basic statistics for the monthly groundwater levels by tree stand age classes

Tree stand age class	Mean ground water level, cm						Mean amplitude, cm			Standard deviation	Coefficient of variation
	annual			half-years		growing season	annual	winter half-year	summer half-year		
	mean	min	max	winter	summer						
I	239	200	269	230	249	239	70	72	68	27.66	0.12
II	272	238	300	263	282	273	62	73	51	22.34	0.08
III	344	316	367	339	349	342	51	58	44	19.47	0.06
IV	274	239	303	267	281	273	64	74	54	23.52	0.09
V	320	303	334	314	325	319	31	37	24	10.47	0.03
VI	289	263	311	282	296	288	48	51	45	18.71	0.07
VII	417	386	439	413	422	416	53	53	53	20.45	0.05
>VIII	236	222	252	231	242	234	30	29	32	11.17	0.05

Explanations: tree stand classes: I – 1–20, II – 21–40, III – 41–60, IV – 61–80, V – 81–100, VI – 101–120, VII – 121–140, >VII – >140 years old.
Source: own study.

Seasonal variability in groundwater levels was also analysed in terms of the distribution of dominant tree species in the stand, i.e. Scots pine, oak and alder (Fig. 5, Tab. 4). Occurrence of these species is most frequently connected with the advantageous forest site type. However, in the Puszcza Zielonka Forest, where a large number of subcompartments have species compositions inadequate to site fertility, pines or oaks are not always found where they should be growing. This problems pertains to alder to a lesser extent. It results from the collected data that oak appeared in the species composition in plots where groundwater levels were relatively deep, deeper than in plots overgrown by pine. The mean distance from the ground surface to the groundwater table was 4.22 m in stands with oak and 3.28 m in stands with pine (Tab. 4). Averaged monthly levels for all species are strongly correlated ($r > 0.933$, Fig. 5). The greatest amplitudes of groundwater levels were recorded in plots with oak.

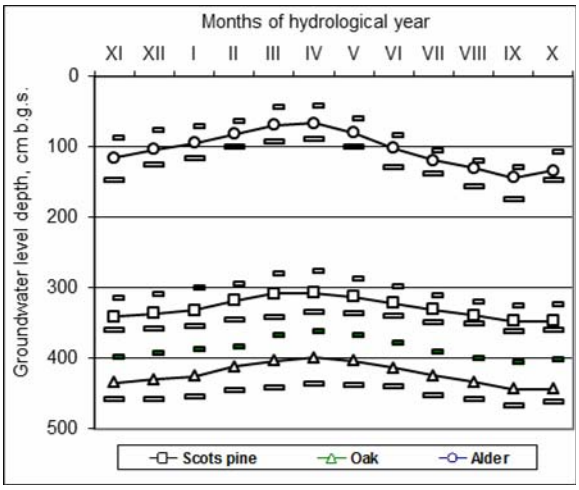

Fig. 5. Minimum (-), mean and maximum (–) monthly groundwater levels depending on tree stand dominant species; source: own study

Table 4. Selected basic statistics for monthly groundwater levels depending on tree stand dominant species groups

Wells groups by tree stand dominant species	Mean ground water level, cm						Mean amplitude, cm			Standard deviation	Coefficient of variation
	annual			half-years		growing season	annual	winter half-year	summer half-year		
	mean	min	max	winter	summer						
Scots pine	328	303	348	323	333	326	46	53	38	17.13	0.05
Oak	422	385	450	417	427	419	65	67	62	26.25	0.06
Alder	103	82	125	89	118	107	43	48	39	14.47	0.15

Source: own study.

The greatest differences were found between curves of groundwater levels for the groups of the shallowest and deepest wells (Fig. 6). This may be explained by the fact that shallow wells, fed mainly by precipitation, distinctly respond to precipitation inflow or its lack by a change in groundwater levels, which is manifested in a more marked lack of uniformity in the course of the curve illustrating their variation. In contrast, deep wells, fed by ground water reserves, exhibit a greater stability of water levels, thus leading to a flatter course of the curve illustrating their monthly variation.

What is interesting, the greatest differences in mean monthly water levels were shown for the group of the deepest wells (Tab. 5). This means that despite the slow response to inflow and losses of water resources from the saturation zone, differences in water table depths in successive hydrological years are much greater than in shallower wells.

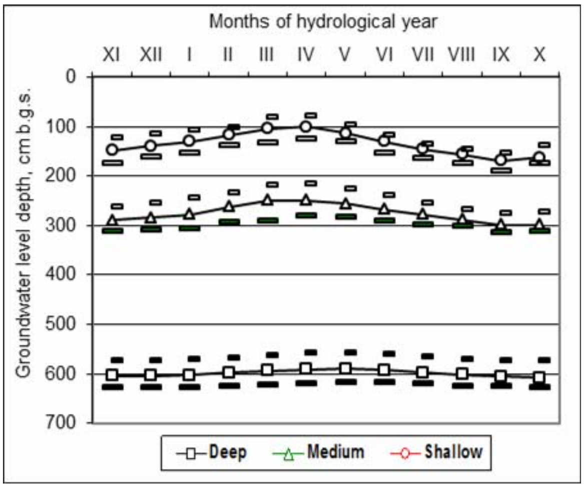

Fig. 6. Minimum (-), mean and maximum (–) monthly groundwater levels by well depth groups; source: own study

Table 5. Selected basic statistics for monthly groundwater levels depending on well depth groups

Well depth	Mean ground water level, cm						Mean amplitude, cm			Standard deviation	Coefficient of variation
	annual			half-years		growing season	annual	winter half-year	summer half-year		
	mean	min	max	winter	summer						
Deep wells	599	567	623	599	599	597	56	57	55	23.86	0.04
Medium wells	275	246	299	269	281	273	53	61	44	19.39	0.07
Shallow wells	135	116	155	123	146	136	39	46	32	13.12	0.10

Source: own study.

DISCUSSION

Based on the results of earlier studies it may be stated that variation of groundwater levels may not always be clearly assessed due to the typically high variation of physico-geographical parameters, synergistically influencing ground water table depths [MILER 1997; MILER, PRZYBYŁA 1997]. Short-term variation results from the fluctuation of weather conditions (e.g. in the course of one year). In turn, long-term variation over a greater area may be connected mainly with climate change [ECKHARDT, ULBRICH 2003; IPCC 2007]. In specific cases this may also result from anthropopressure, e.g. intensive urbanisation, while in forests one of the potential causes may be related with tending interventions [SMERDON *et al.* 2002].

When analysing the course of changes in groundwater table levels in the Puszcza Zielonka Forest we may observe seasonal fluctuations. These changes occurring within one year are obviously connected with periodical climate change, causing rise culmination or regression of groundwater tables. Characteristic phenomena are high water levels in the spring period and regression lasting to the end of the hydrological year.

Courses of averaged monthly groundwater tables in the analysed years of 2001–2009 were very similar, irrespective of the criterion used in grouping or the methods of analysis applied to the collected results. Naturally the smallest similarity of seasonal changes was found between the group of the shallowest and deepest wells ($r = 0.811$). Shallow wells, fed mainly by precipitation, distinctly respond to this phenomenon or its lack by changes in groundwaters, which is manifested in the greater inequality of the curve illustrating its variation. In turn, deep wells, fed mainly by ground reserves, exhibit greater stability of groundwater levels. Nevertheless, this dependence was not as strong in other comparative analyses concerning forest sites or dominant tree species in the stand.

Observations of groundwater levels, conducted in four forest site types found most commonly in the Puszcza Zielonka Forest depending on the age of stands, showed that on average the groundwater table was lying the shallowest in the alder swamp forest site and ash-alder swamp forest site, while it was deepest in the fresh coniferous forest site. It needs to be stressed that groundwater was found relatively deep in swamp sites. Causes for this situation may be connected with land reclamation operations conducted in the past, which traces may still be observed in the form of locally still dense networks of open ditches. Although at present in most cases they are not maintained, they may still have a considerable effect on the groundwater levels within its limits.

The conducted investigations did not confirm different fluctuations in seasonal changes in the position of the groundwater tables in the age classes of stands. No confirmation was found for the hypothesis, reported in earlier studies, concerning variability in the rise of groundwater tables depending on the depth of its deposition. Obtained discrepancies result most probably from the application of short measurement periods applied in the initial stage of the study in the Puszcza Zielonka Forest (e.g. MILER *et al.* [2003], GRAJEWSKI [2004] and GRAJEWSKI, OKOŃSKI [2007]). With the extension of measurement periods earlier results were becoming increasingly specific and could be verified in some cases (e.g. GRAJEWSKI *et al.* [2009; 2013]).

CONCLUSIONS

1. In the studies conducted in the Puszcza Zielonka Forest seasonal variation in groundwater levels, dependent on forest site types, age classes of stands, the dominant tree species in the stand and the depth of groundwater tables, is generally very similar and resembles the continental type with the maximum in the spring, recession lasting to September and a slow rise starting from October. The season of groundwater table concentration for most investigated aquifers was found in April.
2. Earlier literature data from the Puszcza Zielonka Forest on a marked shift in the date of groundwater table concentration between the shallowest and deepest wells were not confirmed in this study.

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Sezonowa zmienność poziomu wody gruntowej w Puszczy Zielonka

STRESZCZENIE

Słowa kluczowe: *Puszcza Zielonka, sezonowa zmienność stanów wody gruntowej, woda gruntowa w lasach*

W pracy omówiono sezonowe wahania zwierciadła wód podziemnych na podstawie wieloletnich obserwacji w kompleksie leśnym Puszcza Zielonka. W latach 2001–2002 zainstalowano tu 132 studzienki do pomiaru stanów wód gruntowych, których lokalizacje dobierano w taki sposób, aby reprezentowane były podstawowe typy siedlisk leśnych i główne gatunki lasotwórcze Puszczy oraz wiek drzewostanów. Pomiary prowadzono w latach 2001–2004, a w wybranych 50 punktach kontynuowano je do roku 2009. Z cotygodniowych wyników pomiarów obliczono średnie stany miesięczne, łącząc je w grupy według: typów siedliskowych lasu, dominującego gatunku w drzewostanie, wieku drzewostanu oraz głębokości zwierciadła wody. Podział na studzienki z płytko (0÷100 cm p.p.t.), średnio (101÷200 cm) i głęboko (>200 cm) zalegającym zwierciadłem wody gruntowej przyjęto arbitralnie, kierując się zakresem zmienności zaobserwowanych stanów.

Sezonowa zmienność stanów wody gruntowej zależy głównie od czynników abiotycznych. Cechy drzewostanów wpływają na ich dynamikę jedynie modyfikująco. W lesie świeżym odnotowano nieco większe wahania wód niż w olsie. Brak jest wyraźnych zależności dynamiki stanów wody od klasy wieku drzewostanów. Generalnie istnieje ujemna korelacja między zmiennością stanów wody gruntowej a głębokością jej zalegania, jednakże w przeprowadzonych badaniach nie potwierdzono hipotezy dotyczącej istnienia wyraźnego przesunięcia czasowego krzywych opisujących zmienność stanów wody gruntowej w zależności od siedlisk, gatunków drzew, wieku drzewostanu czy głębokości zalegania wody.