INFRASTRUKTURA I EKOLOGIA TERENÓW WIEJSKICH
INFRASTRUCTURE AND ECOLOGY OF RURAL AREAS

Nr 6/2008, POLSKA AKADEMIA NAUK, Oddział w Krakowie, s. 83–97
Komisja Technicznej Infrastruktury Wsi
Commission of Technical Infrastructure of the Polish Academy of Sciences-Cracow Branch

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WATER RELATIONS DURING TWO HYDROLOGICAL YEARS IN SWAMPY AREAS IN THE *SIEMIANICE* FOREST EXPERIMENTAL STATION

Summary

In recent years researchers have focused increasingly on climatic changes taking place in nature (increasing air temperature, decreasing precipitation totals). These imply changes in components of water balances and in practice changes in water relations both on the global and local scale. At present site overdrying is considered to be the biggest threat [Pierzgalski 2007].

The aim of the study is to present water relations in the forest swampy areas in a forest district (the Marianka Forest District) of the Siemianice Forest Experimental Station in hydrological years of 2005 and 2006.

The investigations showed that analysed catchments, despite being located in swampy areas, are characterized by periods of water depletion in ditches. In analysed watercourses runoff was recorded from mid-November 2004 to the beginning of June 2005, while in the next hydrological year it was recorded again from mid-November, but this time longer to mid-June 2006. In relation to ground water of the catchment area a predictable relationship was observed of the water table level at the locations of observation wells. The wells located in the top sections of the catchment had water table the deepest below the ground level, while wells in valleys had water tables at the most shallow levels. It may also be stated that wells situated in higher areas (watershed), are characterized by a slightly bigger variation in the ground water table during the year than it was the case with wells located at lower points (in valleys). Both analyzed hydrological years (2005 and 2006) showed a similar pattern of ground water table at individual sites. Moreover, a marked cyclicity was recorded in the elevation of the water table, i.e. water level rising in autumn and lowering in summer months (as a result of changes in plant transpiration). The relationship of ground water levels with different forest sites found in the analyzed catchments confirms the dependence on the site moisture level variant. Water was lying at the most shallow levels in the ash-alder swamp forest site – a marshy site, while it was markedly the deepest in fresh mixed coniferous forest sites – a fresh site type. When analyzing changes in the ground water levels in terms of stand age classes we may clearly observe the seasonal variation and similar patterns of changes. Water lay the most shallow in stands of age classes V and VI. The level was significantly deepest in age class IV. The above dependencies pertained both to the hydrological year 2005 and 2006.

Key words: the Siemianice Forest Experimental Station, swampy areas, ground water level, surface water level

INTRODUCTION

Water resources are a major factor affecting the forest environment. For this reason their sustainable management and protection are an object of concern for foresters as well as an object of interest on the part of biologists, conservationists and engineers designing structures regulating water relations in the forest [Cepielowski and Pienkos 1995].

In recent years researchers have pointed out with increasing frequency to the climatic changes affecting nature (increasing air temperatures, decreasing precipitation totals). These imply changes in the components of water balance and in practice also changes in water relations both on the global and local scale. At present site overdrying is considered to be the biggest threat [Pierzgalski 2007].

Water conditions are some of the most important factors modifying forest sites. Depending on site moisture variants (dry, fresh, moist, swampy and riparian) the tolerance of trees to changes in ground water levels varies. These changes may be cyclical or permanent and in extreme cases they may even lead to steppization or swamping [Tyszka 2004]. Moreover, the future of forest marshes is also doubtful, although in recent years they have again become valued and at present are considered especially valuable in the forest landscape. ”An increasing number of people understand the necessity (...) to prevent the lowering of ground water levels and to preserve the most valuable meadows and peatlands” [Pawlaczyk et al. 2002].

THE OBJECTIVE AND METHODOLOGY OF THE STUDY

The objective of the study is to present water relations in forest marshes in one of the Forest Districts (the Marianka Forest District) of the Siemianice Experimental Forest Station in hydrological years of 2005 and 2006.

Towards the end of 2004 hydrological studies were initiated in the Siemianice Experimental Forest Division. The first stage consisted in the analysis of existing natural and engineering infrastructure of this object. The materials from forest divisions, site inspections, soil and ground surveys, as well as large-scale maps, etc. were thoroughly analysed. Following these analyses it was decided to select two experimental plots microcatchments, for further studies. The selected microcatchments are situated almost entirely in swampy areas. The microcatchments of 34.23 and 30.61 ha, respectively, are located in the Marianka Forest District. Then in the microcatchments a total of 18 observation bore-holes were made. Work on each of them was completed at the drilling to the ground water table. These wells represented three location variants: in watershed areas, in slopes and in valleys of the catchments. In the bore holes, PCV pipes with a diameter of 50 mm were placed, with their bottom sections incised several times along a 0.5 m section to facilitate free inflow of water. From the top wells were sealed with a PCV cork to prevent possible contamination from getting into the pipe. Ground water levels were measured once a week and the recorded result was read accurate to ±0.5 cm. The area of each microcatchment was drained by a ditch collecting and discharging water from the analysed plots. Water gauging stations were established on both ditches in the profiles closing the catchments. Water depth in the ditches was measured once a week. Readings from the staff gauges was accurate to ±0.5 cm. Additionally the Thompson weirs were installed at the closing profiles. Thus it was possible to calculate water flow based on literature formulas.

RESULTS AND DISCUSSION

Figures 1, 2, 3 and 4 present variation in water levels in the two watercourses (ditches), draining water from the analysed microcatchments in relation to daily precipitation totals (annual precipitation totals in hydrological years of 2005 and 2006 were 514.5 mm and 591.4 mm, respectively). The highest levels recorded in the hydrological year of 2005 were 46.3 cm (23 April 2005) in catchment I and 56.7 cm (21 May 2005) in catchment II, while in the hydrological year of 2006 they were 56 cm (catchment I on 28 January, 4 and 11 February, 4, 18 and 25 March 2006) and 51 cm (catchment II on 18 February 2006).

Both catchments, despite being located entirely in swampy areas, have periods with no water observed in the ditches. In hydrological years of 2005 and 2006 lack of water was observed from July to October. Water levels in the ditches were poorly correlated with precipitation totals.

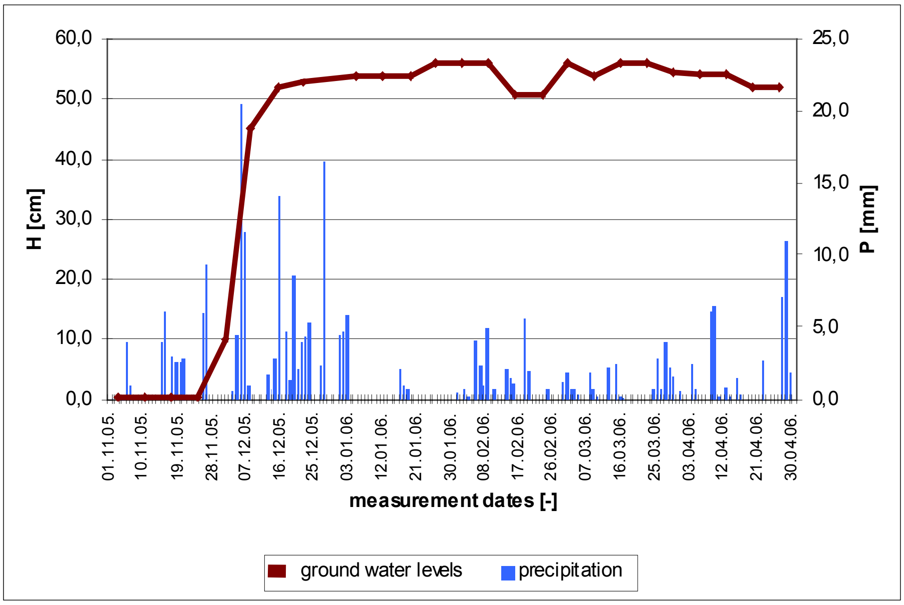

Figure 1. Water levels in the ditch draining water from catchment I in relation to daily precipitation totals in the winter half-year in hydrological year of 2006

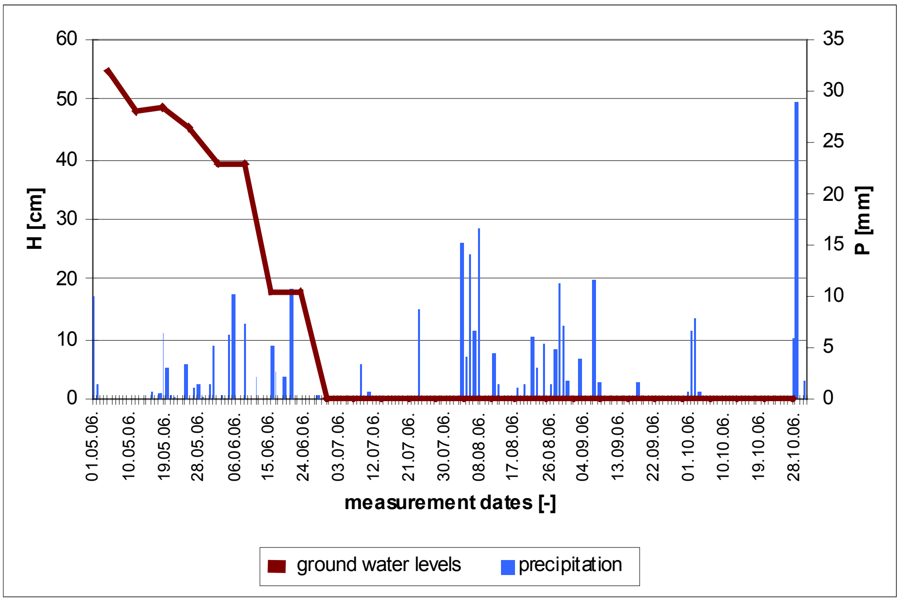

Figure 2. Water levels in the ditch draining water from catchment I in relation to daily precipitation totals in the summer half-year in hydrological year of 2006

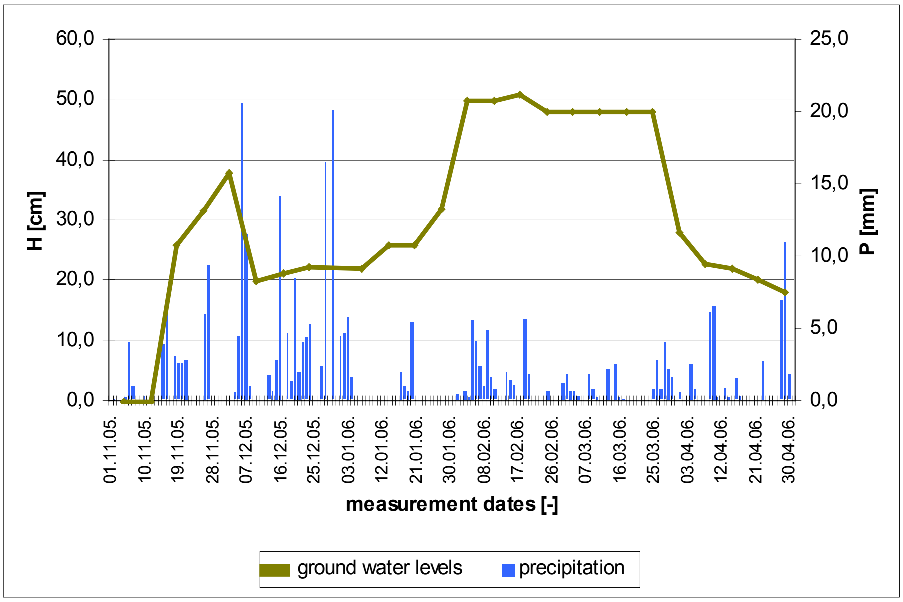

Figure 3. Water levels in the ditch draining water from catchment II in relation to daily precipitation totals in the winter half-year in hydrological year of 2006

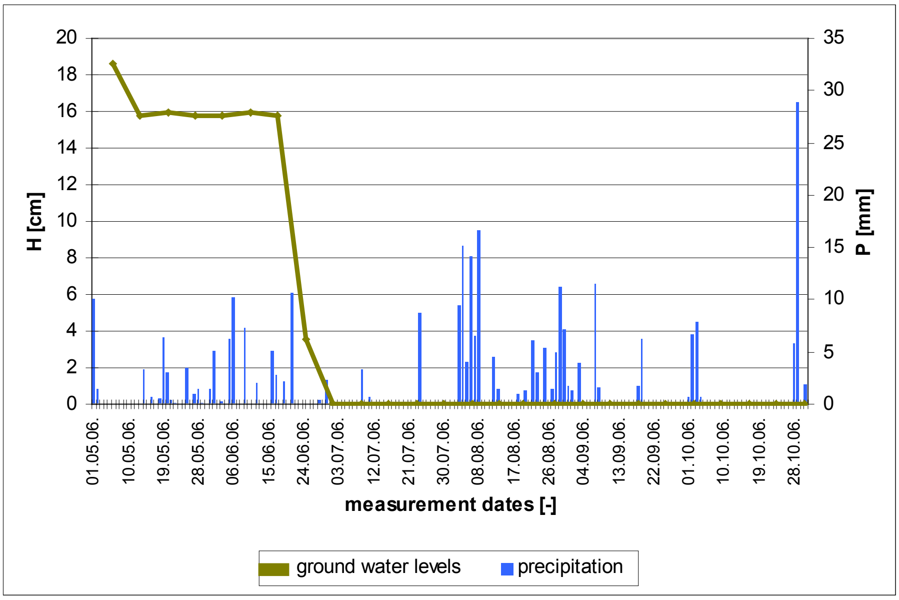

Figure 4. Water levels in the ditch draining water from catchment II in relation to daily precipitation totals in the summer half-year in hydrological year of 2006

Flow intensity was calculated using hydraulic formulas. In case of the ditch located in catchment I the formula for flow intensity takes the form:

$$Q = 0.014\ (H - 47.0)^{2.5} \quad [l/s] \tag{1}$$

while for the ditch in catchment II it is:

$$Q = 0.0144\ (H - 19.8)^{2.5}\ [l/s] \tag{2}$$

The above formulas were developed based on calibration of weirs.

In the first weir at a level of 47.0 cm and lower, no water flows in the ditch. In the other weir it was the case for a level of 19.8 cm and lower.

The mean specific runoff in the hydrological year of 2006 was 1.24 [$l \cdot s^{-1} \cdot km^{-2}$] (Table 1) and it was lower by approx. 70% from the mean runoff for the Wielkopolska region (Table 2).

Table 1. Mean, maximum and minimum specific runoffs from the catchments in hydrological year of 2006

Analysed period	Runoff [$l \cdot s^{-1} \cdot km^{-2}$]		
	mean	maximum	minimum
Winter half-year	2.41	11.22	0.00
Summer half-year	0.08	1.33	0.00
Vegetation season	0.59	11.22	0.00
Hydrological year	1.24	11.22	0.00

Table 2. Maximum, minimum and mean specific runoffs for the Wielkopolska region [Miler 1994]

Analysed parameter	Runoff [$l \cdot s^{-1} \cdot km^{-2}$]
mean maximum runoff	21.75
mean minimum runoff	0.93
mean runoff	4.24

Tables 3 and 4 present mean values and other statistics of ground water level measurements in the catchments belonging to the Marianka Forest District, the Siemianice Experimental Forest Division, in the vegetation seasons of 2005 and 2006, and in hydrological years of 2005 and 2006.

Figure 5 shows that the curves for ground water levels plotted for the most shallow, medium and deepest wells do not exhibit marked differences. The shift in time for the replenishment of ground water was not observed between the distinguished groups of wells. Regular courses of all analysed plots indicate these waters are supplied mainly by precipitation.

Table 3. Mean values and other statistics of ground water levels in two catchments in the Marianka Forest District, the Siemianice Experimental Forest Division in the vegetation season and the entire hydrological year of 2005 [p.p.t. = under ground surface]

Nr	Vegetation season*					Hydrological year 2005				
	$\bar{h}$ [cm p.p.t.]	h_{min} [cm p.p.t.]	h_{max} [cm p.p.t.]	Δh [cm]	σ [cm]	$\bar{h}$ [cm p.p.t.]	h_{min} [cm p.p.t.]	h_{max} [cm p.p.t.]	Δh [cm]	σ [cm]
1	90.0	127.0	28.0	99.0	28.9	74.5	127.0	20.0	107.0	35.0
2	118.6	161.0	58.0	103.0	32.0	102.0	161.0	46.0	115.0	38.0
3	72.1	104.0	18.5	85.5	26.3	57.3	104.0	10.0	94.0	32.1
4	138.0	175.5	48.0	127.5	43.0	122.6	175.5	34.0	141.5	50.9
5	184.9	225.0	114.0	111.0	37.3	166.4	225.0	99.0	126.0	43.0
6	68.1	106.0	8.0	98.0	31.1	50.9	106.0	6.0	100.0	37.8
7	138.4	179.5	67.0	112.5	36.3	119.4	179.5	54.0	125.5	43.0
8	158.2	196.0	92.0	104.0	34.6	140.6	196.0	75.5	120.5	40.4
9	152.5	191.0	80.5	110.5	37.7	134.4	191.0	63.5	127.5	43.0
10	47.3	87.5	2.0	85.5	26.4	35.3	87.5	-1.0	88.5	29.5
11	134.6	183.0	55.0	128.0	42.8	114.3	183.0	26.0	157.0	48.6
12	119.8	160.0	41.0	119.0	39.5	101.3	160.0	27.5	132.5	44.2
13	126.3	170.0	28.0	142.0	42.2	107.2	170.0	22.0	148.0	47.0
14	179.0	232.5	98.0	134.5	43.4	161.6	232.5	92.0	140.5	46.2
15	237.8	276.5	187.0	89.5	35.6	229.1	276.5	187.0	89.5	32.5
16	186.2	229.0	106.5	122.5	45.6	175.0	229.0	106.5	122.5	42.4
17	114.6	163.5	33.0	130.5	46.2	95.9	163.5	32.0	131.5	48.8
18	180.2	232.0	102.0	130.0	44.2	163.4	232.0	90.0	142.0	45.9

- wells located in valleys,
- wells located in slopes,
- wells located in watersheds.

* - the vegetation season was assumed to be that part of the year in which mean decade air temperature was over 5°C. In the hydrological year of 2005 the vegetation season lasted from 1 April to 10 November (224 days)

Table 4. Mean values and other statistics of ground water levels in two catchments in the Marianka Forest District, the Siemianice Experimental Forest Division in the vegetation season and the entire hydrological year of 2006 [p.p.t. = under ground surface]

Nr	Vegetation season*					Hydrological year 2006				
	$\overline{h}$ [cm p.p.t.]	h_{min} [cm p.p.t.]	h_{max} [cm p.p.t.]	Δh [cm]	σ [cm]	$\overline{h}$ [cm p.p.t.]	h_{min} [cm p.p.t.]	h_{max} [cm p.p.t.]	Δh [cm]	σ [cm]
1	84.9	147.0	18.0	129.0	38.9	69.2	147.0	18.0	129.0	38.1
2	117.1	198.0	48.0	150.0	40.4	99.6	198.0	48.0	150.0	40.1
3	78.1	154.0	23.0	131.0	36.7	61.6	154.0	15.0	139.0	36.8
4	130.2	182.0	24.0	158.0	48.3	121.3	182.0	24.0	158.0	46.9
5	184.7	253.0	102.0	151.0	45.4	168.3	253.0	102.0	151.0	43.4
6	68.8	127.0	9.5	117.5	35.9	52.3	127.0	6.0	121.0	36.7
7	132.2	210.0	51.0	159.0	43.3	116.1	210.0	51.0	159.0	42.5
8	156.4	211.0	79.0	132.0	41.2	140.9	211.0	79.0	132.0	40.2
9	151.0	217.0	64.0	153.0	46.2	137.3	217.0	64.0	153.0	43.3
10	50.3	112.0	1.0	111.0	34.0	35.3	112.0	0.0	112.0	33.4
11	126.8	196.0	31.5	164.5	50.8	110.7	196.0	31.5	164.5	48.8
12	116.9	183.0	31.0	152.0	48.4	100.5	183.0	31.0	152.0	47.0
13	121.5	188.0	10.0	178.0	53.3	106.9	188.0	10.0	178.0	49.8
14	172.0	236.0	77.0	159.0	52.5	160.3	236.0	77.0	159.0	47.5
15	216.2	275.5	135.0	140.5	51.5	218.8	275.5	135.0	140.5	43.7
16	175.0	235.0	71.0	164.0	58.1	172.1	235.0	71.0	164.0	48.6
17	106.6	162.0	29.0	133.0	51.4	91.7	162.0	29.0	133.0	49.5
18	171.9	231.0	75.0	156.0	52.9	161.1	231.0	75.0	156.0	48.2

* - the vegetation season was assumed to be that part of the year in which mean decade air temperature was over 5°C. In the hydrological year of 2006 the vegetation season lasted from 1 April to 31 October (214 days).

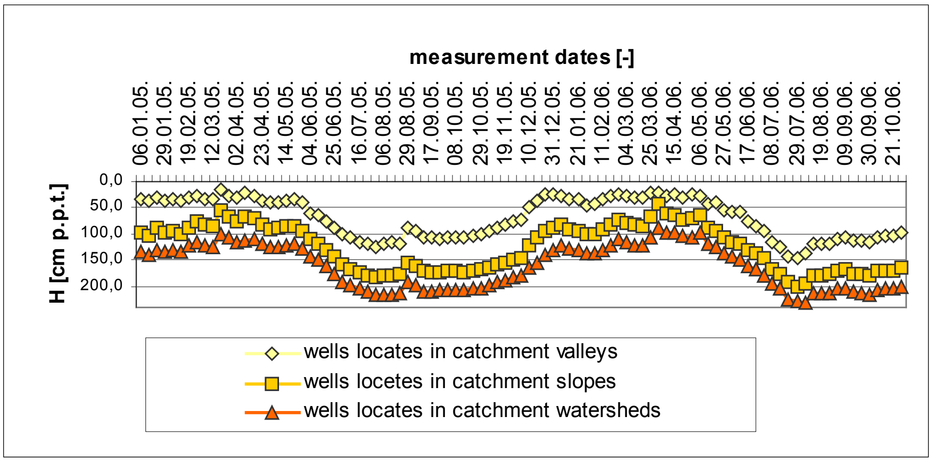

Figure 5. Mean weekly ground water tables for three groups of wells (the most shallow, medium and the deepest) from 06.01.2005 to 28.10.2006 [p.p.t. = under ground surface]

Basic characteristics of the three groups of wells are presented in Table 5 from which it results that the wells located in valley areas of the catchments are characterized by ground water table lying the most shallow under the ground, while the wells located in the watershed sections of the catchments exhibit the deepest mean ground water table. It may also be observed that wells located on higher grounds (watersheds) are characterized by a slightly bigger variation in the ground water table throughout the year than it is the case with those located at lower altitudes (in the valleys).

Table 5. Basic characteristics of three groups of wells differentiated by altitude [p.p.t. = under ground surface]

Depth group	Ground water level [cm p.p.t.]			Standard deviation [cm]
	Mean	Minimum	Maximum	
Valleys	68.8	-1	183	45.5
Slopes	126.1	10	235	51.3
Watersheds	161.2	51	276.5	54.4

The strong correlation of ground water levels between the three distinguished groups of wells is shown by the correlation matrix (Table 6).

Table 6. The correlation matrix for the three groups of wells, distinguished on the basis of their location in the catchment

Group of wells	shallow	medium	deep
shallow	1.00	0.98	0.97
medium	0.98	1.00	1.00
deep	0.97	1.00	1.00

Determined correlation coefficients are statistically significant ($\alpha < 0.05$)

Both analysed hydrological years (2005 and 2006) were characterized by similar patterns of ground water tables in individual sites (Figs. 6, 7). The cyclicity of changes in the position of the water tables was also marked. This confirms the commonly known fact, frequently reported in literature, that in the summer months ground water tables lie at lower depths. This process results from increased transpiration recorded in that period.

The above mentioned Figures 6 and 7 illustrate ground water levels in different forest sites in the investigated catchments. The water table was found to lie most shallow in ash-alder swamp forest and moist broadleaved forest sites, while it was definitely deepest in fresh mixed coniferous forest sites. The above dependencies are confirmed in both analysed hydrological years (2005 and 2006).

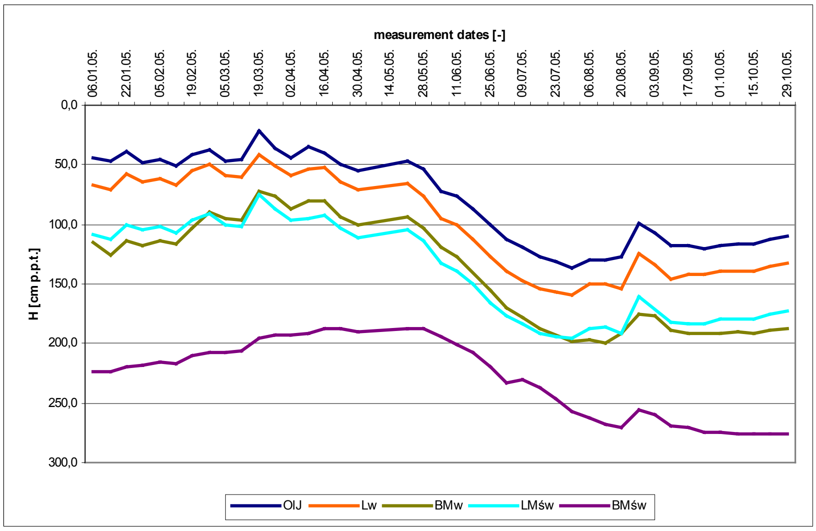

Figure 6. Ground water levels in different forest sites, the Marianka Forest Division, hydrological year 2005 [p.p.t. = under ground surface]

where: OLJ – ash-alder swamp forest, Lw – moist broadleaved forest, BMw – moist mixed coniferous forest, LMśw – fresh mixed broadleaved forest, BMśw – fresh mixed coniferous forest.

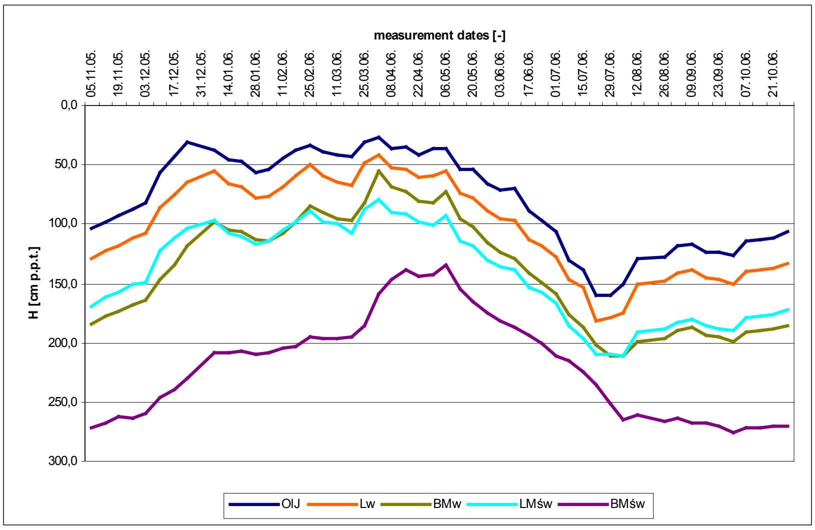

Figure 7. Ground water levels in different forest sites, the Marianka Forest Division, hydrological year 2006 [p.p.t. = under ground surface]

where: OLJ – ash-alder swamp forest, Lw – moist broadleaved forest, BMw – moist mixed coniferous forest, LMśw – fresh mixed broadleaved forest, BMśw – fresh mixed coniferous forest.

Table 7 contains basic parameters concerning the position of ground water tables in relation to the location of gauging points (wells) in different forest site types.

Table 7. Mean values and statistics of ground waters in wells located in a specific forest site type in hydrological years 2005 and 2006 [p.p.t. = under ground surface]

ŚTL	OlJ	Lw	BMw	LMśw	BMśw
h_{max} [cm p.p.t.]	198 22.07.06.	217 22.07.06.	253 05.08.06.	211 05.08.06.	276,5 15.10.05.
h_{min} [cm p.p.t.]	-1 19.03.05.	6 22.01.05. 24.12.05.	10 01.04.06.	75,5 19.03.05.	135 06.05.06.
$\bar{h}$ [cm p.p.t.]	80.1	101.7	141.1	140.8	223.5
Δh [cm]	199	211	243	135,5	141,5
σ [cm]	47.9	54.5	55.6	40.1	39.2

Dependencies between the depth of ground water tables between distinguished sites is shown in the correlation matrix in Table 8. These correlations are strong and even very strong (Lw, LMśw), around 1.

Table 8. Correlation matrix for ground water levels in analysed sites

ŚTL	OlJ	Lw	BMw	LMśw	BMśw
OlJ	1.00	0.99	0.96	0.99	0.75
Lw	0.99	1.00	0.97	1.00	0.77
BMw	0.96	0.97	1.00	0.97	0.89
LMśw	0.99	1.00	0.97	1.00	0.78
BMśw	0.75	0.77	0.89	0.78	1.00

Determined correlation coefficients are statistically significant ($\alpha < 0.05$)

When analysing changes in ground water levels depending on age classes of stands seasonal variation and similar patterns of curves are clearly evident. Figures 8 and 9 present ground water levels in different age classes found in analysed catchments. Water was lying the most shallow in age classes V and VI. It was recorded the deepest in age class IV. The above dependencies pertain both to the hydrological year of 2005 and 2006. It is difficult to present a reliable comment in this respect.

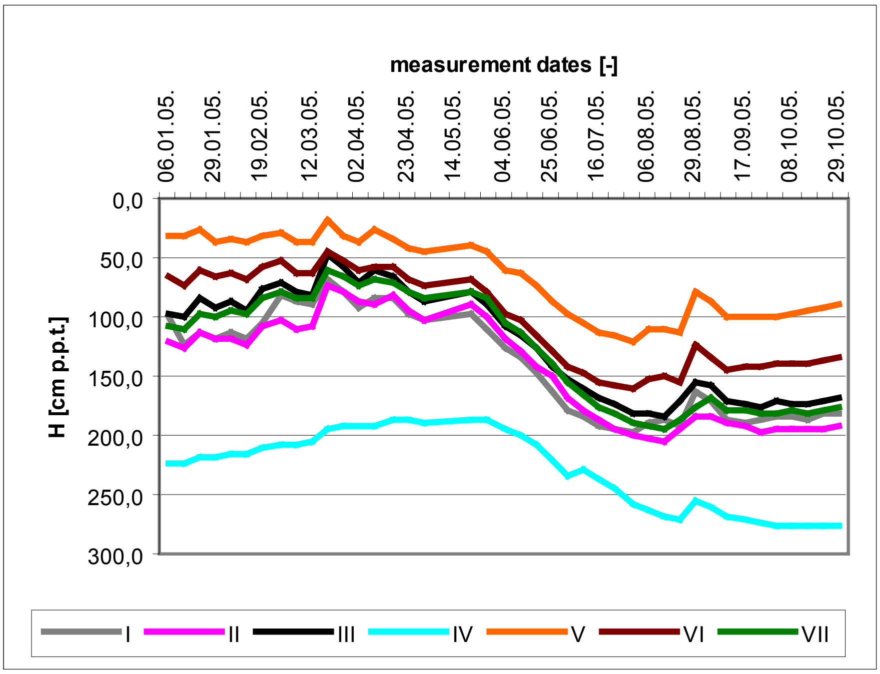

Figure 8. Ground water levels in stands of different age classes, the Marianka Forest Division, hydrological year 2005 [p.p.t. = under ground surface]

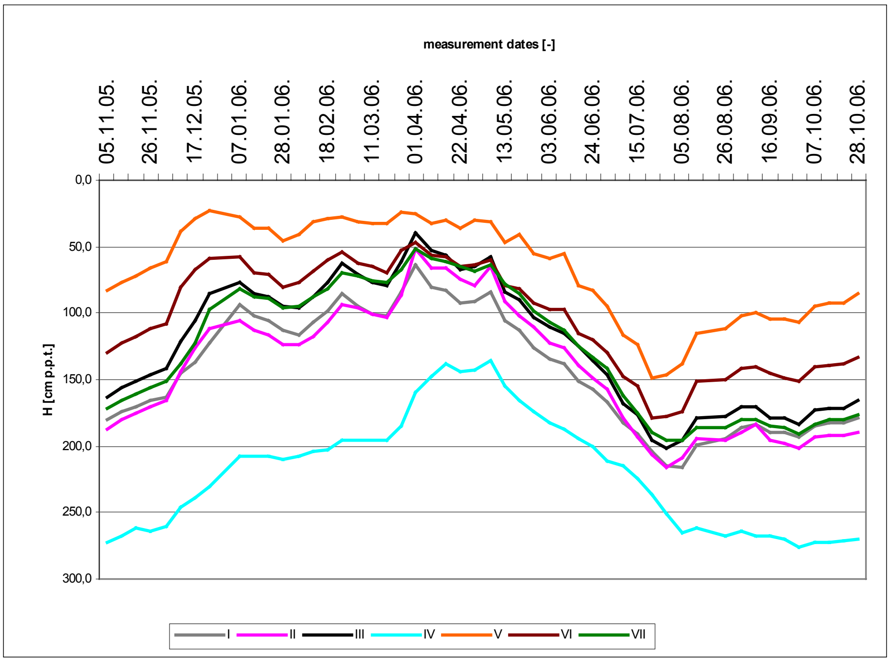

Figure 9. Ground water levels in stands of different age classes, the Marianka Forest Division, hydrological year 2006 [p.p.t. = under ground surface]

Table 9 presents basic parameters of ground water levels in relation to the position of gauging points (wells) in different age classes of stands.

Table 9. Mean values and statistics of ground water levels in wells located in a specific age class of the stand in hydrological years 2005 and 2006 [p.p.t. = under ground surface]

Age class	I	II	III	IV	V	VI	VII
h_{max} [cm p.p.t.]	253 05.08.06.	235 29.07.06.	236 22.07.06.	276,5 15.10.05.	198 22.07.06.	211 05.08.06.	232 13.08.05.
h_{min} [cm p.p.t.]	24 01.04.06.	26 19.03.05.	10 01.04.06.	135 06.05.06.	-1 19.03.05.	6 24.12.05. 22.01.05.	29 01.04.06. 06.05.06.
$\overline{h}$ [cm p.p.t.]	142.2	142.9	122.9	223.5	66.8	103.3	127.9
Δh [cm]	229	209	226	141,5	199	205	203
σ [cm]	48.5	56.1	53.9	39.2	42.5	54.9	58.8

When analysing the position of ground water tables in relation to the age class of stand (Table 10) it may be stated that a slightly weaker relationship is found for correlations in age class IV than it is the case with the other age classes.

Table 10. Correlation matrix for ground water levels in analyzed age classes of stands

Age class	I	II	III	IV	V	VI	VII
I	1.00	0.98	0.99	0.83	0.95	0.98	0.98
II	0.98	1.00	0.99	0.91	0.92	0.95	0.99
III	0.99	0.99	1.00	0.85	0.95	0.98	0.99
IV	0.83	0.91	0.85	1.00	0.70	0.75	0.89
V	0.95	0.92	0.95	0.70	1.00	0.99	0.93
VI	0.98	0.95	0.98	0.75	0.99	1.00	0.96
VII	0.98	0.99	0.99	0.89	0.93	0.96	1.00

Determined correlation coefficient are statistically significant ($\alpha < 0.05$)

CONCLUSIONS

1. Catchments included in the study, despite being located in swampy areas, are characterized by periods with lack of water in ditches. In the investigated watercourses runoff was recorded from mid-November 2004 to early June 2005 and in the next hydrological year – again from mid-November, but slightly for a longer period, i.e., to mid-June 2006.

2. The highest water levels observed in the hydrological year of 2005 were 46.3 cm (in catchment I) and 56.7 cm (in catchment II), while in the hydrological year of 2006 they were 56 cm and 51 cm, respectively. In the first analysed year the maximum specific runoff (calculated as the mean from values calculated for both catchments) was 15.6 $l \cdot s^{-1} \cdot km^{-2}$. In the next year the maximum specific runoff was 11.2 $l \cdot s^{-1} \cdot km^{-2}$.

3. In relation to ground water of the catchment areas a predictable relationship was observed between the level of the water table and the location of the well. Wells situated in top parts of the catchments had their water tables deepest below the ground, while wells from valleys the most shallow. It may also be stated that wells located in higher areas (watersheds) are characterized by a slightly bigger variation in the position of the ground water tables throughout the year than it is the case with those located in lower areas (valleys).

4. Both analysed hydrological years (2005 and 2006) had similar patterns of ground water tables in individual sites. Cyclicity was also evident in changes of water table levels, i.e., they were elevated in autumn and lower in summer months (as a result of changes in transpiration levels). Ground water levels are relatively closely dependent on the forest site. The water was lying the most shallow in ash-alder swamp sites, i.e. swampy sites, while it was markedly deepest in fresh mixed coniferous sites, i.e. fresh sites.

5. When analysing changes in the ground water levels depending on age classes of stands, a marked seasonality is evident and patterns of changes are similar. Water was lying the most shallow in stands of age classes V and VI, whereas it was lying deepest in age class IV. The above dependencies pertained both to the hydrological year of 2005 and 2006.

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