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FACTORS DETERMINING RANGE AND TENDENCIES OF GROUNDWATER LEVEL CHANGES IN KAMPINOS NATIONAL PARK WETLAND AREAS

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Abstract. The marsh zone areas include about 2,440 km^2 in Kampinos National Park, which amount nearly 30% of park and its buffer's surface. The specific characteristic of the KNP marsh zones is presence of shallow groundwater; mean depth to groundwater table is formed from 0.16 do 2.30 m. Range and tendencies of groundwater level changes in marsh zones are related to the influence of geogenic and anthropogenic factors. Among geogenic factors, the most important sense have distribution and seasonality of precipitation, which determine the value of infiltration recharge, evapotranspiration and watercourse drainage of shallow groundwater system. The basis of the researches on defining the role of factors determining range and tendencies of groundwater level changes in KNP, has been regular monitoring observations conducted in the park since 1999. The results of correlation indicate on high diversification of relation: atmospheric precipitation – depth to groundwater level. Determination of trend on the different significance levels provides detaching areas where relation between groundwater levels and precipitation is so high that influence of other environmental factors indicating on depth to groundwater table could be skipped and areas where the relation is so low, which indicates on influence of various factors. Groundwater level in marsh areas are characterized by large dynamic of changes. Since 1999, the beginning of the observations, downward trend of groundwater table has been observed, after 2003 the character of trend has been conversed. Another decreasing trend has started in 2007 and with assumption of previous tendencies, its inversion will occur after 2011 (after extremely dry year). Geostatistical analysis of spatial difference of mean year amplitude of depth to groundwater level enabled the assessment of surface water influence on groundwater level changes. The areas of highest value of amplitudes are localized in southern part of northern marsh belt and central part of southern marsh belt.

Anthropogenic factors such as: water withdrawal and improper draining system, have not changed in recent years, so their influence can be called as "steady" and acceptably to eliminate in case of elaborating of programs of wetland areas renaturalisation.

Key words: renaturalisation, wetland areas, monitoring observations, groundwater level, Kampinos National Park.

INTRODUCTION

The research concerning of the range and tendencies of groundwater level changes to the effort of forecasting the direction of changes were conducted in marsh zones localized in Kampinos National Park.

For the purpose of Ramsar Convention (Convention on Wetland…, 1971) wetlands are areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed 6 metres. Preservation of existing wetland ecosystems and renaturalisation of chosen degraded areas are important elements of ecological improvement strategies, biodiversity protection and water resources formation. In The Water Framework Directive – WFD (Annex V to Directive 2000/60/EC) wetland and marsh areas are not defined in any way, although are marked throughout pointing its function (article I WFD) and environmental purposes (article IV WFD). Requirements of Directive presented in Annex V, point 2.1.1. and 2.1.2 define good quantitative status of water as if the level of groundwater is not subject to anthropogenic alterations such as would result in any significant damage to terrestrial ecosystems which depend directly on the groundwater body.

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Within the KNP, the wetland areas are situated in so-called marsh hydrozones (Krogulec, 2004), the regions with similar hydrodynamic and environmental features, which cover an area of about 142 km^2. Range and tendencies of groundwater level changes in marsh hydrozones are connected to influence of anthropogenic and geogenic factors. Among geogenic factors, the most important sense have distribution and seasonality of precipitation, which determine the value of infiltration recharge, evapotranspiration and watercourse drainage of shallow groundwater system. Anthropogenic factors such as: water withdrawal and improper draining system, have not been changing in recent years.

CHARACTERISTIC OF HYDROGEOLOGICAL AND ENVIRONMENTAL CONDITIONS IN MARSH HYDROZONES

The vide range of previous hydrogeological recognition in KNP, has let to allocated 6 hydrozones in the park (Krogulec, 2004). Spatial configuration of hydrozones refers to a typical for the KNP and its buffer zone belt configuration of the relief surface. The major allocation criteria were differences in dynamic and character of groundwater level changes, mean depth to groundwater table, factors determining recharge and drainage process and environmental conditions (soil types, land use, differences in morphology, etc.). In the vicinity of the KNP following hydrozones were distinguished (Fig. 1):

- the Vistula River flood plain terrace,
- 2 marsh zones (northern and southern),
- 2 dune and eolian zones (northern and southern),
- accumulative-erosive Warsaw–Błonie terrace called Błoński level (with part of the upland).

On account of specificity of recharge and drainage, distinguished hydrozones are partially related to the division of Lasica catchment proposed by Somorowska (2003), who allocated 2 hydrological different regime zones:

- wet, flat, low-laying zone with shallow groundwater, where groundwater table lays to 1.5 m below ground level;
- dry zone of rather diverse morphology with groundwater table located deeper, less than 5 m below ground level.

In the KNP, wetlands are ecosystems, which genesis is associated with water related communities in such an extend that decides on the presence in it of hydrophilic vegetation and accumulation of hydrogenic soils. The wetland areas, in which water occurs at a depth to 0.5 m with possibly, a short spring occurrence on the surface, cover approximately 110 km^2. The moist areas where the water is up to 1 m below ground level cover about 30 km^2. The marsh zones cover an area of about 2,440 km^2 (Fig. 1).

In a generalized lithological profile, typical for the whole Vistula valley, 4 granulometric different beds were distinguished in the region of the KPN. Fine-grained sand mixed with silt-grained sand builds an unsaturated zone and the upper part of the aquifer. Below, there is a layer of small thickness consisted of medium-grained sand. Lower in the profile a clear dichotomy of the aquifer can be marked. In the upper part there are 2 complexes of coarse-grained sediments, sand with gravel, gravel and pebbles and fine-grained sand, silt, sometimes sandy clay at the bottom. The geological building of southern and northern hydrozones is similar. The unsaturated zone in terms of lithological composition mostly corresponds with the saturated zone. Under the 0.4 m thick layer of soil, characteristic for wetlands, there are mostly sandy silts or fine-grained sand covering varying and locally medium-grained sand. Underneath, the aquifer is dual likewise in the whole KNP region.

Lithologic differentiation within the aquifer is well illustrated by hydrogeological parameters of individual complexes. The upper part of the aquifer (up to 17.5 m below ground level) is characterized by the value of hydraulic coefficient in the range from 30 to 71 m/d. In the bottom part of the aquifer, the value of permeability coefficient is significantly lower and takes values less than 30 m/d.

Within the marsh hydrozones 3 types of vegetation communities represented by the various phytosociological units were allocated. The largest area is covered by dry and fresh communities, which cover 53.2% all northern zone communities and 37.9% of southern zone. Most of all natural ecosystems are related to this community but also introduced by man. The group of natural ecosystems is composed of forestry and shrub areas as well as meadows, swards and wastelands. Artificial ecosystem is associated with the planting such as woodlands and shrublands. This unit is often recorded on the desiccated parts of the river valleys, the potential habitats of hornbeam forests on dry ground and in the driest parts of the riverine communities. An important environmental factor is the level of groundwater, which should be occured at 0.4 m below ground level. Periodic floodings are rare but in dry seasons, the groundwater table may occur below 1.5 m below ground level (Szewczyk, Domańska, 2010). Other distinguished units occupy small areas, and their location is mosaic.

The moist community is less differentiate and consist of 2 ecosystems – meadows and forests. It covers 22.0% of northern hydrozone and 13.5% southern hydrozone. The meadows play an important role in retention of surface water thus preventing the mineralization of organic soils (Szewczyk, Domańska, 2010). An important part of this community, especially in the northern hydrozone, are ash-alder riverine forests. This kind of forests stabilize the water balance and are one of the elements deciding of natural water retention (http://www.wigry.win.pl/siedliska/91e0_3.htm, 05.05.2010).

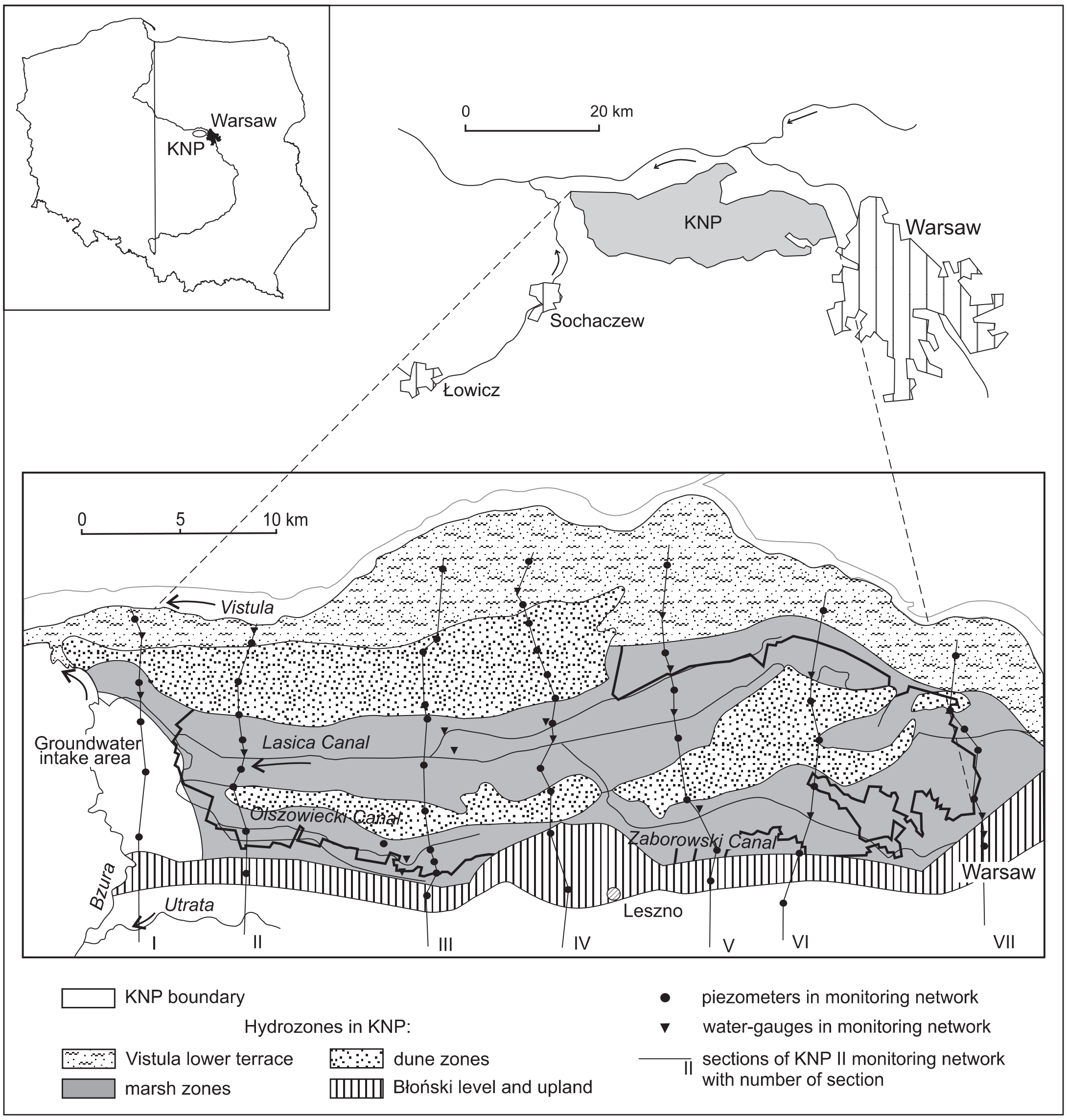

Fig. 1. Location map of the Kampinos National Park (KNP) with type of hydrozones

The third distinguished type, most associated with water, is comprised with marsh communities. It covers 24.8% of northern hydrozone and 48.6% southern hydrozone. Vegetation of this type is created by highsedge rushes and current alders. Marsh communities is characterized by visible clumpy structure. For most of the year, in depressions between the clumps, water should be maintained on the surface.

In the area of marsh zones 8 type of soil were evolved. Scope and structure of different types of soils is complex, multifactorial (Konecka-Betley, 1999) and mosaic.

RANGE OF MONITORING RESEARCHES

Geostatistical analysis of monitoring data in the range of groundwater level, based on hydrodynamic datum, allows for presentation of the conclusions in a scope of characteristic of groundwater level fluctuations. The results are an output to forecast of the groundwater level changes. Water system monitoring is based on manual (regular) and automatic (continuous) observations of groundwater level, which has been conducted since 1999 in 56 piezometres (standard construction – PCV pipes) located in the whole KNP area and its buffer zone. Manual measurements, which are the base of analysis of range and tendency of groundwater level changes, include therefore 11 years or 160 hundred measurements. In the marsh hydrozones: northern and southern, there are located accordingly: 11 and 9 groundwater monitoring points (Fig. 2). Statistical analysis in marsh areas includes 57 hundred of measure-

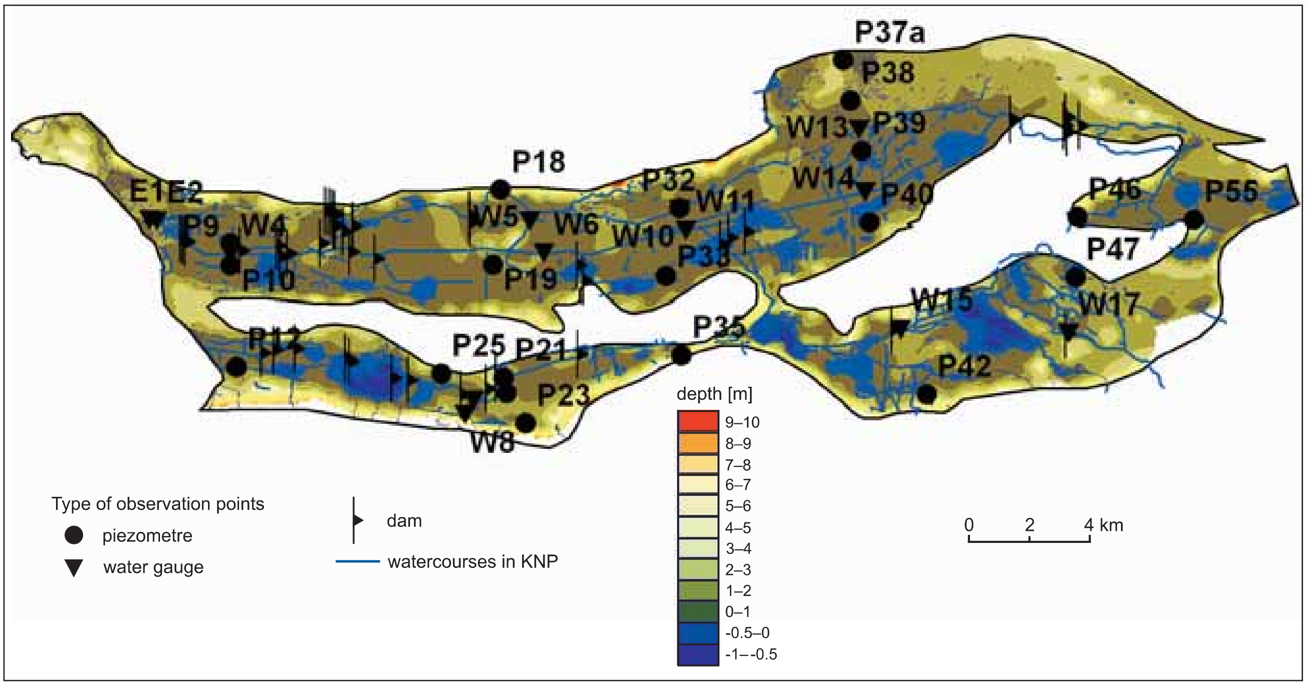

Fig. 2. Groundwater depth in the marsh zone areas with number of monitoring point

ments led regularly in fortnightly intervals. This range of measures and research points location allows for: indicating and characteristic of constant and seasonal tendencies, identifying abnormal values and spatial characteristic of groundwater level changes.

The major aim of an interpretation of the results of geostatistical analysis, based on monitoring observations, is to define factors influencing on range and tendencies of groundwater state changes.

CHARACTERISTIC OF GROUNDWATER LEVEL FLUCTUATIONS IN MARSH HYDROZONES

Specification and characteristic of groundwater level fluctuations was conducted in marsh hydrozones in the KNP area. In the first stage of statistical analysis of monitoring data, assessment of groundwater level tendency of changes was done by designing trend lines. The conducted analysis of observations from 10-year period by drawing trend line in the form y = ax+b (Krogulec *et al.*, 2009) does not allow for firm defining of change tendency direction. Under this circumstances there is no conclusions pointing at permanent marsh zones desiccatin. More reliable matching is obtained by trend line with third degree polynomial equation (Tab. 1).

Series of groundwater level observations in piezometres in analysed hydrozones, represented by statistically significant trend lines, indicate on three characteristic periods of groundwater level changes. Trend line, similar in shape to cosinusoide, has two maxima – in 1999 and 2007 (Fig. 3). These years are beginning of the sequences of dry years and the end of wet ones. Since 1999, the beginning of the observations, the downward trend of groundwater table had been noticed. After 2003 the character of the trend had been obversed. Following decreasing trend has started in 2007 and with assuming previous tendency, its reversal will occur after 2011 (after extremely dry year).

Changeability of the trend lines and their degree of matching for series of the observations from particular piezometres are conditioned by many environmental factors (value of correlation index of trend lines with groundwater levels in a range from 0.16 to 0.57). Environment of groundwater in marsh areas is defined by large dynamic of table level. Amplitudes of changes during the year reach magnitude around 2 m in northern belt and above 3 m in southern (Fig. 4). In northern marsh belt annual, high table level in spring season, holds averagely on the level 0.05–0.20 m below ground level, the lowest occurs in autumn season and reaches depth around 2 m, with mean year around 1 m below ground level for years 1999–2009. Southern belt is an area, where annual floodings averagely reach a height around 0.30 m and in extremely cases almost 0.50 m. In autumn period low level of groundwater table occurs on the depth of 3 m. Average depth, similarly as in

Table 1

Summary of the groundwater level observations in piezometres of marsh hydrozones with the trend lines of changes

Hydrozone	No. of piezometre	Groundwater depth [m]			Amplitude [m]	Average amplitude [m]	Equation of trend line
		year mean	year max	year min			
Northern marsh zone	P9	0.85	1.45	0.13	1.32	0.86	$y = 9E–08x^3 – 5E–05x^2 + 0.0059x + 0.7368$
	P10	0.62	1.11	–0.19	1.30	0.70	$y = 1E–07x^3 – 5E–05x^2 + 0.0062x + 0.5034$
	P18	0.91	1.52	0.30	1.22	0.76	$y = 1E–07x^3 – 5E–05x^2 + 0.0083x + 0.6153$
	P19	1.37	2.14	0.34	1.80	1.11	$y = –7E–08x^3 + 2E–05x^2 + 0.0006x + 1.1859$
	P32	0.85	1.35	0.27	1.08	0.68	$y = 1E–07x^3 – 6E–05x^2 + 0.0058x + 0.8334$
	P33	1.30	2.03	0.59	1.44	1.06	$y = 1E–07x^3 – 7E–05x^2 + 0.0094x + 0.9801$
	P37A	1.18	1.62	0.57	1.05	0.73	$y = 3E–07x^3 – 0.0001x^2 + 0.0156x + 0.6651$
	P38	1.15	1.76	0.10	1.66	0.93	$y = 3E–07x^3 – 0.0001x^2 + 0.0184x + 0.5453$
	P39	0.61	1.26	0.04	1.22	0.91	$y = 2E–07x^3 – 7E–05x^2 + 0.0081x + 0.3966$
	P40	1.47	2.16	0.87	1.29	1.05	$y = 2E–07x^3 – 7E–05x^2 + 0.0091x + 1.2162$
	P46	1.00	1.60	0.25	1.35	0.91	$y = 1E–07x^3 – 6E–05x^2 + 0.0085x + 0.661$
	P55	0.70	1.46	0.32	1.14	0.84	$y = 9E–09x^3 – 1E–05x^2 + 0.0029x + 0.5637$
Southern marsh zone	P12	0.51	1.15	–0.23	1.38	0.82	$y = 8E–08x^3 – 3E–05x^2 + 0.0032x + 0.485$
	P21	0.16	0.98	–0.48	1.46	0.90	$y = 4E–08x^3 – 3E–05x^2 + 0.0049x + 0.047$
	P22	0.68	1.60	–0.16	1.76	1.02	$y = –4E–08x^3 – 8E–07x^2 + 0.0032x + 0.4842$
	P23	1.35	2.41	0.55	1.86	0.89	$y = 2E–07x^3 – 0.0001x^2 + 0.0142x + 1.1185$
	P25	1.67	2.25	1.10	1.15	0.88	$y = 9E–08x^3 – 5E–05x^2 + 0.0076x + 1.406$
	P35	2.30	3.16	1.54	1.62	1.23	$y = 2E–07x^3 – 8E–05x^2 + 0.0119x + 1.8312$
	P42	0.95	1.86	0.25	1.61	1.15	$y = –9E–09x^3 – 3E–06x^2 + 0.0022x + 0.784$
	P47	1.95	2.63	1.09	1.54	1.18	$y = 2E–07x^3 – 9E–05x^2 + 0.012x + 1.5817$

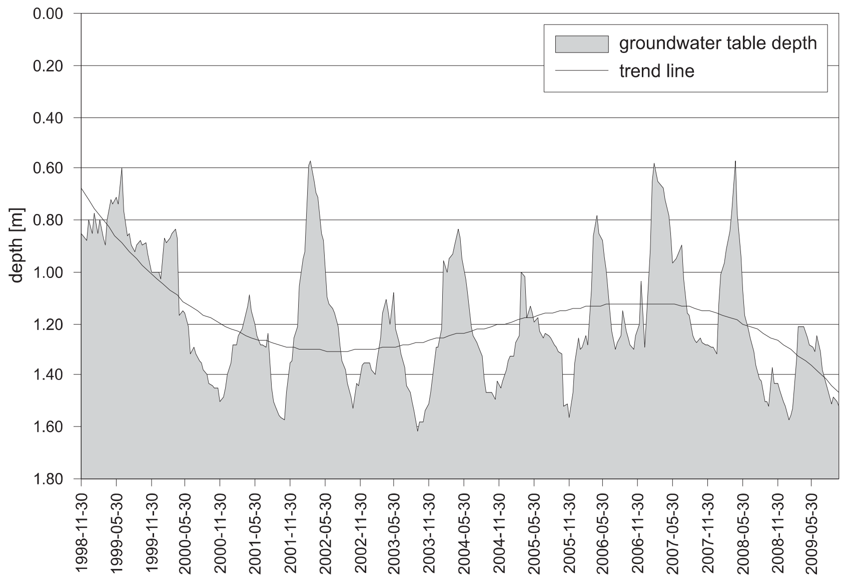

Fig. 3. Trend of groundwater level changes on the instance of the observations in P37A piezometre

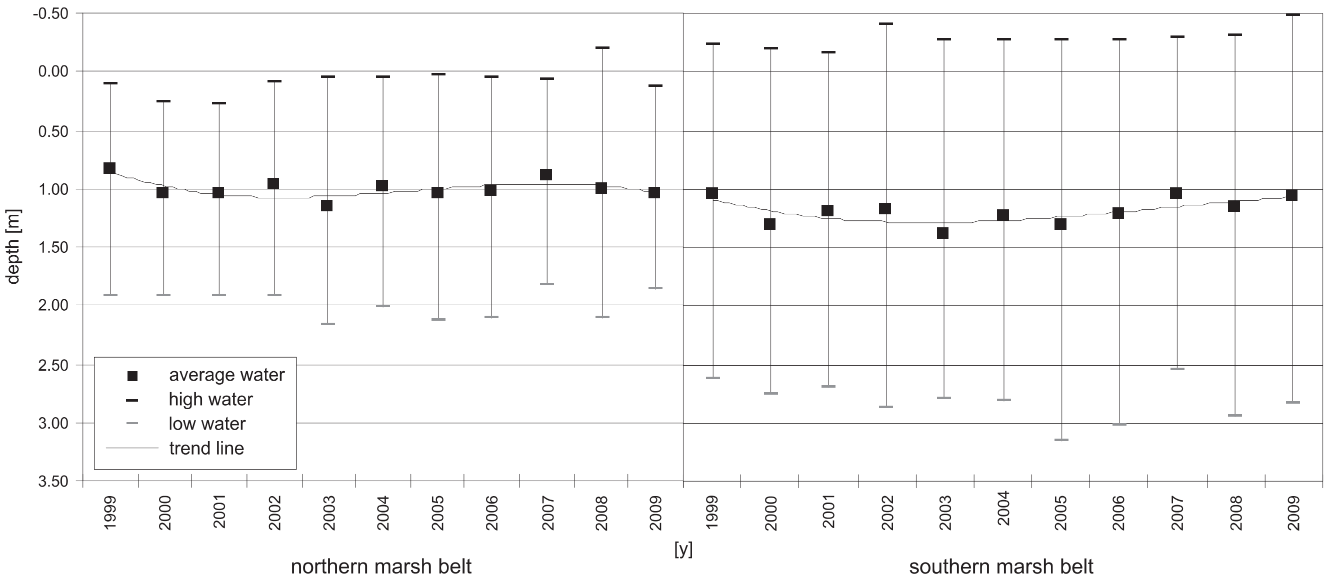

Fig. 4. Range of changeability of groundwater level in marsh belts

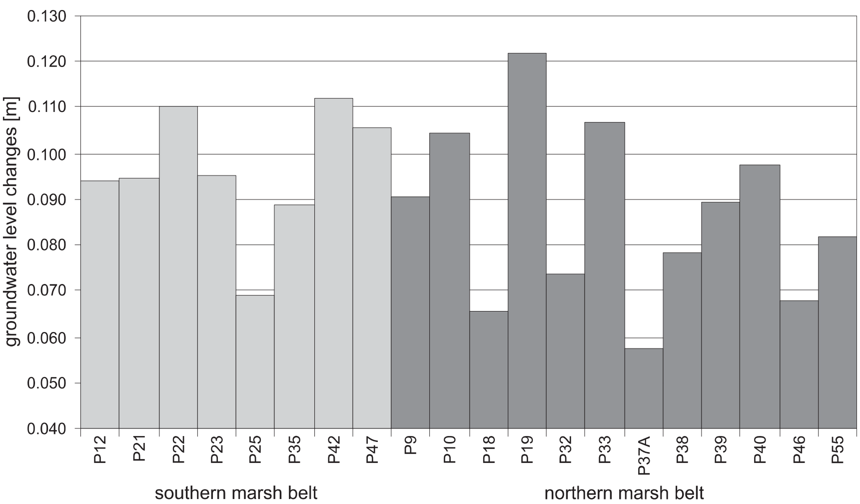

Fig. 5. Average changes of groundwater level in fortnightly intervals in piezometres of marsh hydrozones

northern belt, occurs on the level of 1 m (for years 1999–2009 this value is 1.19 m).

Groundwater level changes were also analyzed by comparing difference between following measurements in particular piezometres (regularly measurements in fortnightly intervals). Average change of table level is 0.086 m/2weeks in northern belt and 0.096 m/2weeks in southern. In particular piezometres this changeability forms between 0.057 m/2weeks and 0.122 m/2weeks (Fig. 5). In the area of northern marsh belt spatial distribution of table level is significantly higher than for the changes occurring in the southern marsh belt area. Described changes indicate on differential retention ability of unsaturated and saturated zone in both belts.

FACTORS DETERMINING CHANGES OF GROUNDWATER LEVEL IN MARSH HYDROZONES

The most important factor determining depth to groundwater table in the marsh hydrozone areas is an infiltration recharge. Value of groundwater recharge was a subject of detailed researches (Krogulec, 2004, 2010). Conducted researches had a character of quantity regional assessment (Tab. 2). Adapted methodology of an assessment of infiltration recharge value involves data and parameters mostly averaged for whole, delineated area or significantly generalized area, which does not give the basis for analysis of changeability of infiltration recharge value. Differentiated

Table 2

Infiltration [mm/year] – summary of different calculation method

Hydrozone	Method of estimation	Infiltration	
		1951–2000	1998–2002
Vistula flood plains	Empirical method	133–166	118–147
	Water Table Fluctuation	–	73
	Numerical method	–	56–95
Swamp areas	Empirical method	133	118
	Water Table Fluctuation	–	73–100
	Numerical method	–	10–44

infiltration recharge values, defined by application of varied methods, are related to adopted, different input data and technique of calculations (Tab. 2). Separated analyses concerning on the influence of evapotranspiration for groundwater level changes were not conducted, assuming that mentioned process limits infiltration recharge value.

An infiltration recharge quantity is mostly connected with precipitation value. On the basis of the data from rainfall stations located in the KNP area and its buffer zone, average precipitation during the period 1986–2009 is 614 mm. According to Kaczorowska's classification (1962), sequences of wet, ordinary and dry years were designated (Tab. 3).

Periods of sequences of dry and wet years (Tab. 3) correspond with maxima of trend lines allocated for particular observations in piezometres. The most significant years were: 2003 (dry), when annual precipitation was 84% of the average precipitation and 2007 (wet), when annual sum was 118% of average from years 1986–2009.

Correlation of groundwater level with precipitation was conducted for each piezometre in marsh hydrozones. The results indicate on notably differentiation of dependence: precipitation – groundwater table depth, which illustrates various values of determination coefficient (Tab. 4). Strength of correlation apparents in significance of trend line. Three levels of significance such as: 0.05, 0.1 and 0.2 were chosen to analysis. Determination of the trend significance at the particular levels results in choosing the piezometres, in which relation between groundwater level and precipitation is so important, that other environmental factors influencing on groundwater level could be ignored (piezometres P9, P32, P40 and P21, P23, P25) and group, where this dependence is very low and influence of other factors needs special consideration (P37A, P38, P46 and P12, P35).

An attempt to correlate the groundwater table fluctuations in marsh hydrozones with vegetation communities and types of soils (Piórkowski *et al.*, 2010; Szewczyk, Domańska, 2010) were also done. Statistical Chi-squared tests were conducted in order to check wheather there is a dependence between groundwater table level and concrete vegetation or soil type occurring in the neighborhood of piezometres. In the first stage of the analysis all piezometres belonged to marsh hydrozones were included. Minimal and maximal groundwater depth values, amplitude and mean amplitude of groundwater table level were compared to vegetation and soil types. A null hypothesis about independence of the characteristic on the level of significance set to 0.05 was assumed. In all calculations value of test statistic was lower than critical value, which was a basis to accept placed

Table 3

Classification of hydrological year type according to precipitation value

Hydrological year type	Percent of average precipitation from years 1986–2009	Hydrological year in period 1999–2009
Extremely dry	<50	–
Very dry	51–74	–
Dry	75–89	2000, 2003, 2005
Ordinary	90–110	2001, 2002, 2004, 2008, 2009
Wet	111–125	2001, 2006, 2007
Very wet	126–149	–
Extremely wet	>150	–

Table 4

Strength of groundwater depth correlation with precipitation value and their significance

Hydrozone	No. of piezometre	Determination coefficient R2	Level of significance		
			0.05	0.1	0.2
Northern marsh belt	P9	0.36	YES	YES	YES
	P10	0.28	NO	YES	YES
	P18	0.25	NO	NO	YES
	P19	0.01	NO	NO	NO
	P32	0.43	YES	YES	YES
	P33	0.21	NO	NO	YES
	P37A	0.08	NO	NO	NO
	P38	0.11	NO	NO	NO
	P39	0.29	NO	YES	YES
	P40	0.41	YES	YES	YES
	P46	0.01	NO	NO	NO
	P55	0.34	NO	YES	YES
Southern marsh belt	P12	0.13	NO	NO	NO
	P21	0.41	YES	YES	YES
	P22	0.22	NO	NO	YES
	P23	0.45	YES	YES	YES
	P25	0.38	YES	YES	YES
	P35	0.17	NO	NO	NO
	P42	0.18	NO	NO	YES
	P47	0.13	NO	NO	NO

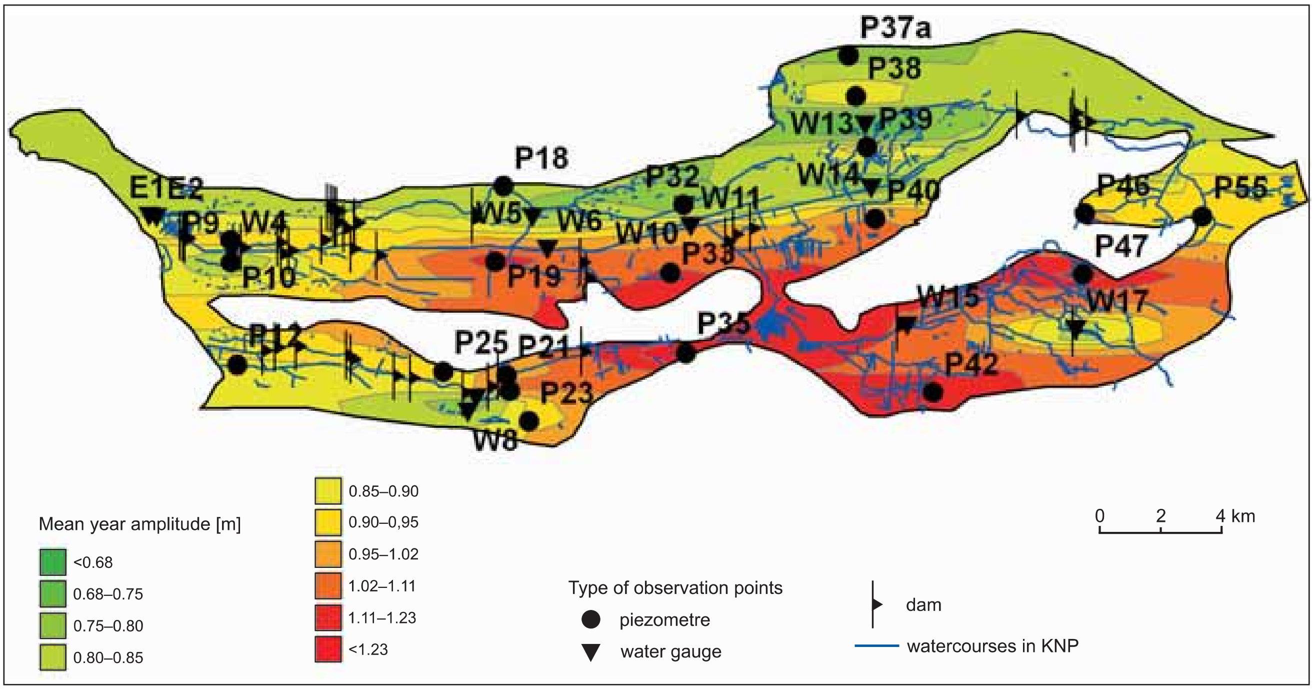

Fig. 6. Map of arrangement of mean annual amplitude of groundwater and surface water in marsh areas

hypothesis about independence. In the second stage groundwater monitoring points, in which groundwater table depth highly depends on precipitation value, were excluded from analysis, having left only points, where this relation is inconsistent or absent. Hypothesis about independence of characteristics was assumed again. All analyzed cases reaffirmed existing hypothesis.

Next research stage was a geostatistical analysis of spatial changeability of mean year groundwater amplitude values, which was done on the basis of the results of groundwater level correlation with surface water level (Krogulec *et al.*, 2009). Spatial arrangement was calculated by ordinary kriging method. The best semivariogram marching was achieved with expotential model with parallely situated anisotropy axis and 7 minimal neighbors to include. Mean standard error was calculated at 0.17. The watercourse dams, stopping river outflow are also presented in the result map. In the areas, where there are no dams on the watercourses, mean amplitudes reach over 1 m (max. 1.23 m). In case of presence numerous objects restraining surface water outflow, amplitude values are in range from 0.48 to 0.68 m. Areas characterized by highest values of amplitudes are located in the southern part of northern marsh belt and in the central part of the southern marsh belt (Fig. 6).

Analysis of location particular observation points is the most proper to explain groundwater level changes in piezometres, where the influence of precipitations is unnoticeable (Figs. 2, 6). Piezometre P12 is situated in the area with the highest dam density, which could directly affects on the range of registered groundwater changes. Piezometres P37A and P38 are located in the neighbor of the Vistula River flood plain terrace, where possibility of river influence on groundwater level fluctuations is high. Piezometres: P35 and P46 are located on the verge of the dune and the marsh hydrozones. In the piezometre P19 groundwater level changes are related to neighbor of the Lasica River and the object retraining surface water flow occurred there.

CONCLUSIONS

The Kampinos National Park is situated in hydrogeological valley unit, typical for Polish Lowland. Protected wetland areas located in the Park were the subject of detailed environmental researches. Planned marsh renaturalization requires diagnosis of the present state and assessment of the tendency and range of water relation changes in this area. Researches were conducted basing on manual groundwater level observations, which have been led in 20 monitoring points located in marsh hydrozones (over 5700 measurements) since 1999 as well as the data elaborated within Project ("Development...") (map of existing vegetation communities and types of soils).

Statistically significant trend lines described by third degree polynomial indicate on typical periods of groundwater level changes. Downward groundwater table trend corresponds with beginning of dry years sequences while increasing trend with beginning of wet years sequences.

The obtained information indicates on directly relation between groundwater level and precipitation value in infiltration recharge function. Detailed correlation of groundwater level with precipitation values in the particular monitoring points reveals that described relation is inconclusive for all monitoring points. Defining of trend significance permits to allocate the regions, where dependence on precipitation is noticeable and the other environmental factors influencing on the groundwater level depth, could be skipped and the group, where this dependence is very low. Statistical Chi-squared test excluded existence of relation between groundwater level and delineated within Project vegetation communities and types of soils. High generalization of vegetation and soil data, in regard of largeness of analyzed area, could not be a basis for description of local environmental conditions and their influence on groundwater table fluctuations in monitoring point.

Geostatistical arrangement of the amplitudes of groundwater depth and in the water courses draining marsh belts, allowed for extracting the areas precisely connected to surface water fluctuations and depended on existing dams. Additionally, analysis of the location explained influence of other factors on water conditions registered in the rest of measure points.

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