A Hydrodynamical Modelling for Testing Effects of Wetlands Restoration- A Case Study in the Kampinoski National Park, Poland

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***Abstract*—**Kampinoski National Park (area of 385,44 km^2) with its buffer zone (area of 385,88 km^2) is a UNES[1]CO Biosphere Reserve and it is a special protection area of NATURA 2000 network which plays an essential role in nature conservation in the EU. Valuable wetland areas in the Kampinoski National Park are exposed to anthropogenic pressure mainly from the neighboring Warsaw metropolitan area. During the past two centuries, wet areas in the park have been drained and turned into agricultural lands, which reduced significantly natural wetland habitats. The purpose of subsequent simulations on a hydrodynamic model was to identify the hazards and to perform the quantitative evaluation of the results of scenarios of restoration of the northern bog belt within the area of Park.

***Keywords*—**Kampinoski National Park, modelling, Poland, wetland.

I. Introduction

KAMPINOSKI National Park is located where four tributaries: the Bug &Narew, Wkra and Bzura Rivers, merge with the Vistula River (Fig. 1). According to Ecological System of Protected Areas (ESPA) the valleys of these rivers are ecological corridors. The Vistula River valley in Kampinos Forest is especially recognized as an important ecological area in Europe. The area is characterized by a diverse morphology, hydrogeological conditions, geology and vegetation, as well as infrastructure development.

The evaluation of wetland restoration is one of the most important problems discussed in the research on renaturalization. Primary natural relations prevailing within the area of KNP have been interrupted by desiccation and changing swamps into meadows and pastures. In the period of recent decades another hazards occurred, mainly urbanization pressure related to the vicinity of the Warsaw metropolitan area, resulting in among others: change in use of the land.

Preservation of the existing wetland ecosystems and renaturalization of selected degraded areas constitute important elements of the strategy of eco-development, biodiversity and shaping of water resources. In Water Framework Directive [11] waterlogged areas, swamps or water-marsh areas are not defined in any way, though are recognized by distinct indication of their functions (article 1 of WFD) and environmental goals (article 4 of WFD). Requirements of the Directive presented in Appendix V, item 2.1.1 and 2.1.2. define good quantitative status of water that is when the level of groundwater is not subject to anthropogenic changes which could cause any substantial damages to land ecosystems dependent directly on parts of groundwater.

Protected water-marsh areas, as defined by the Ramsar Convention (1971) [11], are the areas of bogs, silt and peat bogs or water bodies, natural and artificial, permanent and temporary, with standing or flowing water, with fresh, brackish or salt water, including sea water, the depth of which during the low tide does not exceed 6 m.

Wetland areas, namely the ecosystems the origin of which involves habitats hydrated to such a degree that it determines the presence of them in hydroliphic vegetation with accumulation of hydrogenic soil formations cover around 14,2 000 ha of KNP.

Fig.1 Localization of the Kampinoski National Park

Wetland areas in which water is present at the depth of up to 0,5 m, with possible, short occurrence on the surface in spring cover ca. 11 000 ha. Damp areas where water is present at the depth of up to 1 m below the ground level cover about 3 thousand ha [3], [4], [9].

Such areas are located in marsh hydrozones [3], namely in the areas with similar hydrodynamic & environmental characteristics separated within the area of KNP. The area of marsh hydrozones covers about 244 thousand ha of Kampinoski National Park, which means that they constitute almost 30% of the park area, including the buffer zone. A specific characteristic of those areas is the presence of shallow

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groundwater levels; average depth to groundwater level falls within the range of from 0,16 to 2,30 m.

The scope and the tendency of changes in groundwater levels in marsh hydrozones are associated with the influence of anthropogenic and geogenic factors. From among the geogenic factors, the distribution and seasonality of infiltration nourishment and evapotranspiration, as well as drainage of shallow groundwater systems by watercourses are of fundamental importance. Anthropogenic factors, that is: intake of groundwater and wrong system of melioration remained unchanged in recent years.

Water monitoring system in Kampinoski National Park is based on manual (regular) and automatic (continuous) observations of groundwater levels carried out from 1999 in 56 piezometers in piezometers located in entire area of KNP and the buffer zone. Thus manual measurements, being the basis for the analysis of the scope and tendencies of changes in groundwater levels cover 15- year base that is more than 20 000 measurements. In the northern marsh hydrozone 11 monitoring points are located [5], [8], [9].

In the first stage of statistical analysis of monitoring data, tendencies of changes in groundwater levels were assessed by marking out trends lines. Routes of observation of groundwater levels in piezometers in the analyzed hydrozone, represented by statistically significant trend lines, indicate three characteristic periods of changes in groundwater levels. The mean values of groundwater levels period (1999-2013) (Fig. 2) were the basis of hydrodynamical model.

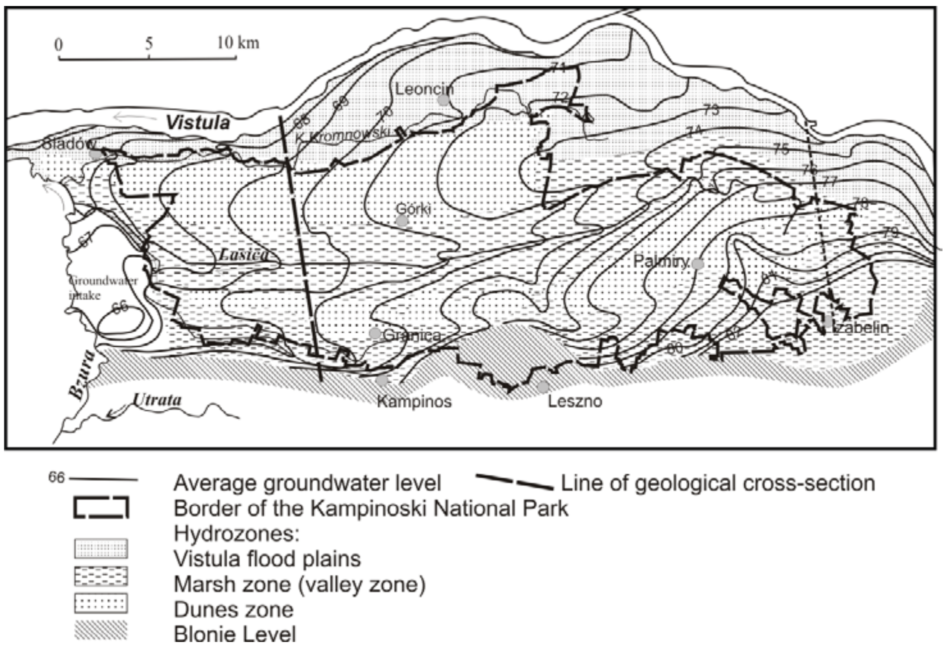
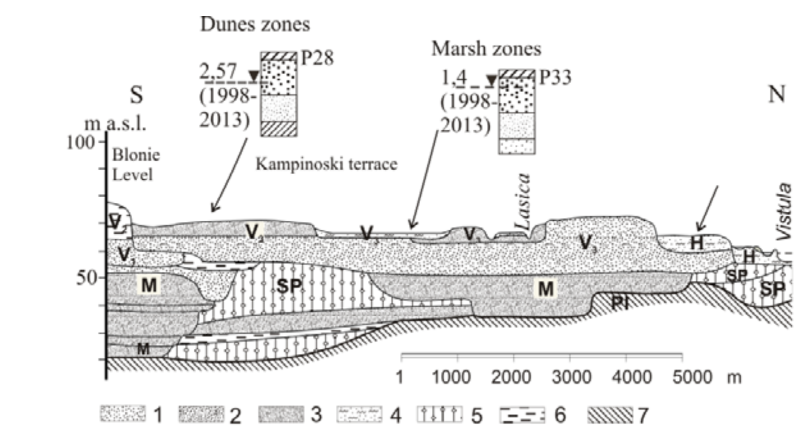


Fig.2 Localization of hydrozones



1 - sand and gravel, 2 - medium sand, 3 - fine-grained sand, 4 sand, tilly sand, 5- till, 6 - icedammed lake clay, 7 - exposure of Pliocene deposits

H - Holocene; V_1 - Lower Vistulian; V_2 - Middle Vistulian; V_3 - Upper Vistulian;
E - Eemian Interglacial; MP - Middle Polish Glaciation; M - Masovian Interglacial;
SP - South Polish Glaciation; Pl - Pliocene
P28 - profile of piezometer

Fig. 3 Geological cross-section

II. Hydrodynamic Model

The subject of model tests was a shallow hydrogeological unit of valley type in which the Kampinoski National Park is located**.** Water-carrying layer is composed of alluvial sandy & gravel layers (Fig. 3). In the floor of alluvial deposits weakly permeable moraine deposits and Pliocene clays occur most often. Within the whole package of the Quaternary deposits there are also two large erosive structures filled to substantial extent with sandy and gravel material [4].

Land surface of the modeled area was transformed to a significant extent as a result of intensive eolian processes that took place in late Pleistocene and early Holocene [1]. Dune hills belts clearly dominant in the morphology determine to a significant extent contemporary hydrographic layout of the area (Fig. 3). Formation of dune belts resulted in arising of local watershed zones. Separated systems of groundwater circulation [4] and local watershed zones result in the fact that flow of groundwater towards the main drainage base, namely Vistula river bed, is limited to a significant extent. Western direction of groundwater flow is also favored by inclination of the surface of terraces [2], [6]. The water balance, calculated in the Visual MODFLOW program is not the balance of the mass in strict sense, since it refers to the volume of water and volume of flow in the modeled system. ZoneBudget application available in the Visual MODFLOW packet was used to calculate the balance of the modeled of the aquifer. First, the total water balance of the area was calculated. Percentage error of the balance reaches the level of 0,01%, which shows that the solution is not affected by the error resulting from the iterative procedure. ZoneBudget program allows one to perform calculations of water balance in the designated zones of the modeled area [4]. It allowed for the quantitative characterization of the various balance elements in each zone.

A. Schematization Of Hydrogeological System

For the purposes of the model tests, water-bearing system confined from the north by the bed of the Vistula River, from the west by the bed of Bzura, from the south along the edge of Blonie Level have been separated from hydro-geological area. Eastern boundary has meridian course and runs perpendicularly to the system of hydroizophypses line. The floor surface of the level is determined by weakly permeable deposits occurring in the base of alluvia.

Hydrogeological system has been represented by means of orthogonal discretization grid with a step of $\Delta x = \Delta y = 100$ m. Size of the adopted step corresponds to resolution of numerical model of the surface of the area. Then the discretization of space along the axis was performed dividing the tested water-bearing level into 3 sub layers. Variable thickness of the first level was determined through spatial interpretation of ceiling and floor surface. A numerical model of the surface of the area was created for this purpose. The model has been created with the use of Topo to Raster method in the package of ArcGIS Desctop 9.3 software of ESRI Company. Height data were saved in the raster format in 100 x 100 m resolution, which corresponded to the model's resolution. Archive drilling profiles and results of electroresistant probings were used to interpret the floor surface. The data was transformed into raster format by means of the Kriging method. The last step was to assign the height data to discretization grid [2].

B. Model Identification

The series of measurements of groundwater levels conducted in observation network of the Kampinoski National Park constituted the basis for the model identification. The measurements performed in the monitoring network were used for this purpose. The averaged values of the level from this period served as the point of reference for numerical calculations under the set filtration conditions. The difference between the measured conditions and the calculated ones is the most commonly applied criterion of model's assignment. The error analysis was used when evaluating the compliance of the calculated hydraulic value with the values measured in the area. Model verification procedure was conducted based on the four most often used methods to record this type of errors [7], [10].

In order to estimate the values of the aforementioned errors, the calibrating file containing the data of the observation vector along with the location of measuring points were developed. These data could have been compared with the values calculated for each variant of input model parameters in automatic mode. The aim was to minimize the modeling errors using the guess-check-and-improve method. The identified values included the center conductivity and spatial distribution of supply. The analysis of sensitivity of the model was also performed at the stage of calibration with the aim to minimize the objective function. The procedure consisted in multi-dimensional analysis of the identified parameters and the search for such set of values that would minimize the difference between measured and calculated levels of the system. A high degree of the fit of the model to the real system was achieved which is reflected in very low error values. The average absolute difference between the measured and calculated level is less than 14 cm, with the maximum rest at the level of 34 cm. Also the values of other errors confirm the strong analogy between the model and the system.

III. Results Of Model Calculations

Basic result of model calculations was the identification of the function of the modeled object's condition**.** It consists in determination of the spatial layout of the hydraulic height for the accepted system structure and used extortions. The results constituted the basis for determining the elements of the flow balance. The groundwater filtration flow including spatial layout of the water-bearing system supply was also represented.

Numerical model of a filtration field made it possible to perform water balance calculations of the analyzed system. Water balance is the balance of the total inflow and outflow within the frameworks of the hydrogeological system.

ZoneBudget program allows one to perform calculations of water balance in the designated zones of the modeled area [2], [4]. It allowed for the quantitative characterization of the various balance elements in each zone.

Reneutralization projects concern the northern marsh hydrozone. Planned actions aim to increase the groundwater level in order to maintain the already existing ones and to reconstruct the drained marsh zones. Hydrodynamic model research concern all hydrozones designated within the frameworks of KNP, however, particular attention is paid to the largest northern marsh belt.

Marsh belts should be identified with drainage zones of the first aquifer. Clear differences in the structure of water balance in each zone confirm that the division of the area into hydrozones developed by Krogulec (2004) [4] is reasonable.

A. Numerical prognostic calculations

Subsequent simulations on a hydrodynamic model were of prognostic nature. Their purpose was to identify the hazards and to perform the quantitative evaluation of the results of scenarios of renaturalization of the northern marsh belt within the area of the Kampinoski National Park.

After analyzing possible (planned or expected) scenarios of hydro-geological conditions within the area of KNP, the quantitative balance calculations were performed in relation to:

- intensification of groundwater intake within the area of research (scenario 1),
- effects of transformation of the actual hydrographic network layout on the marsh area (scenario 2),
- changes of the Vistula River state (scenario 3).

The basis for evaluation of the effects was the calculated difference between the current system condition – hydrodynamic model, and the condition obtained under extortions conditions assigned to particular scenarios prognostic calculations. Additionally, the quantitative evaluation of the elements of water balance of the northern marsh belt and their changes as a result of prognostic simulations were made.

B. Danger Assessment In Connection To The Intensification Of Groundwater Intake (Scenario 1)

The current intake of groundwater in the area of Kampinoski National Park is focused mainly in peripheral areas. Total expense of intakes exploiting the first water-bearing level is at the level of 2683,8 m^3/d, namely 4,6 m^3/d km^{-2}, which is only a small proportion of renewable resources of the system. The purpose of calculations was to identify what effect on water relations of the northern marsh belt the intensification of the intake may have. The groundwater intakes are not located on the examined area. Ways of using the land, the neighborhood of Warsaw and the attractiveness of the land makes that in the future the demand on groundwater may be increased. Since operational resources of intakes located there are much higher than the current operation, it was decided to model reflect the increased groundwater intake in the existing intakes. The scenario was assumed in which the intake of the groundwater would double in relation to the value being observed now. The obtained distribution of the function of the condition was compared to the current state. The differential map constitutes a qualitative, spatial description of the impact of the intake intensification on groundwater of the first level. The calculations of water balance with regard to the northern marsh belt were conducted. The changes of the components of the balance have given the basis for the quantitative evaluation of the transformation of water relations in that area.

Increased exploitation resulted in the reduction of the level reaching up to 140 cm. The biggest transformation of the hydrodynamic condition is associated with direct environment of the intakes; on the remaining area of the filtration field the changes are not big. This also applies to the northern marsh belt where different components of the balance yielded only to slight transformations. This allows one to state that the double increase in the value of the intake with maintaining its current spatial distribution is not a significant hazard for water relations within the area of the northern marsh belt [10].

C. Assessments Of The Possibility Of Renaturalizing The Marsh Belt By Changing The Arrangement Of The Hydrographic System (Scenario 2)

The naturalization of marsh ecosystems within the area of Kampinoski National Park requires the activities aiming at the restoration of the natural arrangement of water relations. It consists ultimately in the necessity of restoration of the primary arrangement of the hydrographic system, significantly transformed in the period of 70s and 80s as a result of melioration works. The main element of the melioration network of the northern marsh belt is the artificial river bed of the Lasica channel. This element is currently the main axis of the drainage of groundwater, as well as receives the waters from the network of smaller melioration ditches.

In projects of renaturalizing the area, the different scenarios of changes which purpose is, among others, to raise the level of groundwater are considered.

The most drastic scenario, assumes the total liquidation of the currently functioning melioration network (filling up the ditches and the channels). The earlier described model of the field of filtration tarred for to the current condition was used for the purposes of calculations. The system's response to the change of the extortions layout was the transformation of its hydrodynamic condition. Transformations of the water balance are considerable and are shaped at the level close to 10% of the current marsh zone resources. Obviously, the drastic limitation of river drainage role took place. Growth of the groundwater level caused intensification of the groundwater evaporation (more than 23% as compared to the current condition). The largest changes on the side of revenues concern the limitation of the underground inflow from the adjacent areas.

The growth of the groundwater level being the result of liquidation of the melioration network is worth mentioning. The maximum values of growth, even when considering the intensification of losses related to evapotranspiration, exceed

100 cm. Such large increase of the water level certainly would be favorable for reneutralization of marsh belt. Nonetheless, it should be noted that at the same time it would imply drastic transformation of water relations of the area, which would affect the environmental conditions of the currently functioning peat bogs and waterlogged areas. What is more, due to the fact that the simulation was conducted for the conditions of the set filtration, obtained value change of the level must be treated as averaged size. It should be assumed that the periods of hydrological year during which the system level may be even higher than the calculated one will be observed. First of all, it will apply to the period of thaw, which always involves intensification of the supply stream. It may be assumed that after liquidation of the melioration network within the area of marsh belt, temporary watercourses and surface reservoirs waters may be formed. These watercourses can drain the excess of water towards the west, in accordance with the surface terrace. Therefore, potentially, in spite of liquidation of the melioration network, the new drainage zones may be created on the marsh belt area. Nonetheless, the drainage size in relation to the current level would be certainly limited.

D. Assessments Of The Possibility Of Renaturalizing The Marsh Belt By Changing The Levels Of The Vistula River (Scenario 3)

The bed of the Vistula River in the examined area constitutes the main axis of drainage for the regional system of groundwater circulation. Among projects of renaturalizing the waterlogged areas within Kampinoski National Park a possibility of raising the groundwater' levels by damming up the Vistula waters is considered. This variant is by assumption extremely expensive (economically and socially) and involves radical transforming, and partially even destruction of currently operating ecosystems e.g. in the area of flood terraces of the Vistula river. The purpose of model calculations was in this scenario the identification of whether such actions might be effective in case of restoration of marsh areas within the area of the Park. Similarly, as in case of previous variants, the transformation of the system's condition within the area of the north marsh belt was analyzed thoroughly.

Model calculations consisted in the assignment of new values of the condition for the part of the bank surface associated with the bed of the Vistula River. It was researched what the response of the water-bearing system for damming up of the Vistula waters by 2 m will be. The results of calculations are unambiguous in this case. Change of level of surface waters leads to the transformation of the groundwater level. Nonetheless, the impact zone in the set damming up level is, in principle, limited to the area of lower terraces. Beyond the area located in belt of 500 to 2000 m from the river bed, the change of the groundwater level is fractional. Therefore, it can be stated that the damming up of the Vistula waters would be completely ineffective in case of the renaturalization of the northern marsh belt. The changes of the components of the balance are in this case limited to the area located near the river bed of Vistula. The confirmation of conducted research are also the monitoring observations conducted in the period of high levels on the Vistula river indicating also maximum 1800 m range of the impact of high levels of the Vistula river on groundwater.

IV. Conclusions

The Kampinoski National Park is located in hydrogeological valley unit, typical for the Polish Lowland. The waterlogged protected areas existing here were the object of detailed environmental research. The planned renaturalization of marsh within the area of the park requires the diagnosis of the present condition and indication of tendencies and scope of changes in water relations in these areas.

A dominant factor determining the levels of groundwater within the area of KNP are the conditions of infiltration and drainage of groundwater associated mainly with systems of groundwater' circulation. The results of correlation of the groundwater' levels indicate a substantial diversity of dependencies: precipitation – depth to the water surface of the groundwater. The determination of the importance of the trend on particular levels enables the separation of regions where the dependence of levels from the precipitation is so significant that other environmental factors affecting the height of the groundwater level may be ignored as well as regions where this dependence is very low, what indicates the impact of other factors.

The current intake of underground waters does not create hazard to water relations of the northern marsh hydrozone. Also the intensification of collection with maintaining, at the same time, its current spatial distribution does not carry the risk of a significant transformation of water balance in this zone. The analysis of different variants of the renaturalizing of the northern marsh belt proved that the total elimination of the melioration network in that area would be the most effective. Nonetheless, it should be pointed out that so drastic interference in the environment would bring negative environmental effects.

Actions consisting in the change of the course of the river bed of Lasica will not result in such a significant growth of the level of groundwater. It should also be taken into account that in the first period after conducting the actions, the undesirable reduction of water levels may occur. The reconstruction of the condition of the hydrodynamic system would be in this case spread in time, and the measurable effects of the actions would be detectable no sooner than after the full "restoration" of the river bed.

Concept of renaturalizing the marsh area by damming up the Vistula waters owing to high economic and social costs and low effectiveness should be rejected.

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