MODELLING OF HYDROLOGICAL SYSTEM OF THE BIEBRZA VALLEY

Mioduszewski W.[1)], Querner E. P.[2)] Ślesicka A.[1)]

Abstract: To improve and maintain the necessary environmental conditions for the ecosystems in the valley Biebrza river it is important to have a proper understanding of the hydrological systems. The study concentrates on understanding the regional groundwater flow and its relation with the surface water, taking into consideration water quantity and quality. The paper focuses on the modelling of the hydrological system in terms of the sources of water fluxes to the different ecosystem types in the Biebrza Lower Basin.

The physically–based groundwater and surface water model SIMGRO was used to gain insight in the regional groundwater flow patterns. The SIMGRO model simulates the regional water movement in the unsaturated zone, the saturated zone and the surface water in an integrated manner. Using the results of the groundwater models, flow lines were calculated, giving information on the sources of water flows to the different ecosystem types in the river basin. The numerical calculations with the field measurements of groundwater table together with analysis of soils and plants allowed to distinguish the discharge and recharge areas and the different sources of water filling of river valley.

Keywords: groundwater, surface water, modelling, flow lines, nature management.

INTRODUCTION

The valley of Biebrza River represents a unique environment of river marginal wetlands with very well developed conations of peat focusing ecosystems. Almost the whole valley is protected within the Biebrza National Park (BNP). One of the dangers for the park is overdrying of the soil, which may be caused by drainage

[1] Water Resources Department, Institut of Land Reclamation and Grassland Farming. Falenty, 05–090 Raszyn, POLAND

[2] Department of Water and the Environment, Alterra.P.O. Box 47, 6700 AA Wageningen, THE NETHERLANDS

works carried out in the past in the river valley and by some natural and antropoghenic changes in the adjacent areas. The result is an accelerated succession towards vegetation types dominated by scrubs and a loss of bio–diversity [OKRUSZKO, 1992].

To improve and maintain the necessary water conditions for the valuable eco–systems in the Biebrza National Park it is important to have a proper understanding of the hydrological systems. The study concentrates on understanding the regional groundwater flow and its relation with the surface water. The work presented in the paper focuses mainly on the methodology of recognising of the hydrological system in terms of the sources of water fluxes with the help of numerical modelling in the Biebrza Lower Basin. The physically–based groundwater and surface water model SIMGRO was used to gain insight in the regional groundwater flow patterns. The SIMGRO model simulates the regional water movement in the unsaturated zone, the saturated zone and the surface water in an integrated manner. Using the results of the model, flow lines were calculated, giving information on the sources of water flows to the different ecosystem types in the river basin. The numerical calculations with the field measurements of groundwater table together with analysis of soils and plants allowed to distiquish the discharge and recharge areas and the different sources of water filling of river valley.

The research presented in this paper is a part of the Polish – Dutch project "Hydrological system analysis in the valley of Biebrza River" [MIODUSZEWSKI, QUERNER, 2002]. The project aimed at the integration of studies carried out by the project partners, focusing on groundwater flow, surface water flow, groundwater and surface water quality and wetland ecosystems. The project has been carried out with support from the Dutch Ministry of Agriculture, Nature Management and Fisheries and the Dutch Ministry of Foreign Affairs.

GENERAL CHARACTERISTICS OF NATURAL VALUES OF THE BIEBRZA NATIONAL PARK

Biebrza National Park (Fig. 1) is the largest national park in Poland. Situated in the northeastern part of the country in the Podlasian Province the park covers an area of 59223 ha. Forests occupy 15547 ha of the park, croplands – 18182 ha and barren lands–famous Biebrza Wetlands, in fact most valuable natural ecosystems – 25494 ha.

Biebrza National Park protects extensive and almost unchanged valley peatlands with a unique diversity of plants, animals and habitats. The Biebrza valley is an important place for waterfowl, therefore it was prescribed in 1995 to the list of the Ramsar convention sites i.e. wetlands of international importance specifically for the waterfowl [MIODUSZEWSKI, QUERNER, 2002].

The largest area among the forest associations is occupied by alder swamp, which grows mainly along the mineral edges of the valley. Large areas are also overgrown with bilberry forests. Relatively smaller areas are covered with bog coniferous forests, spruce forests and riverine willow shrups.

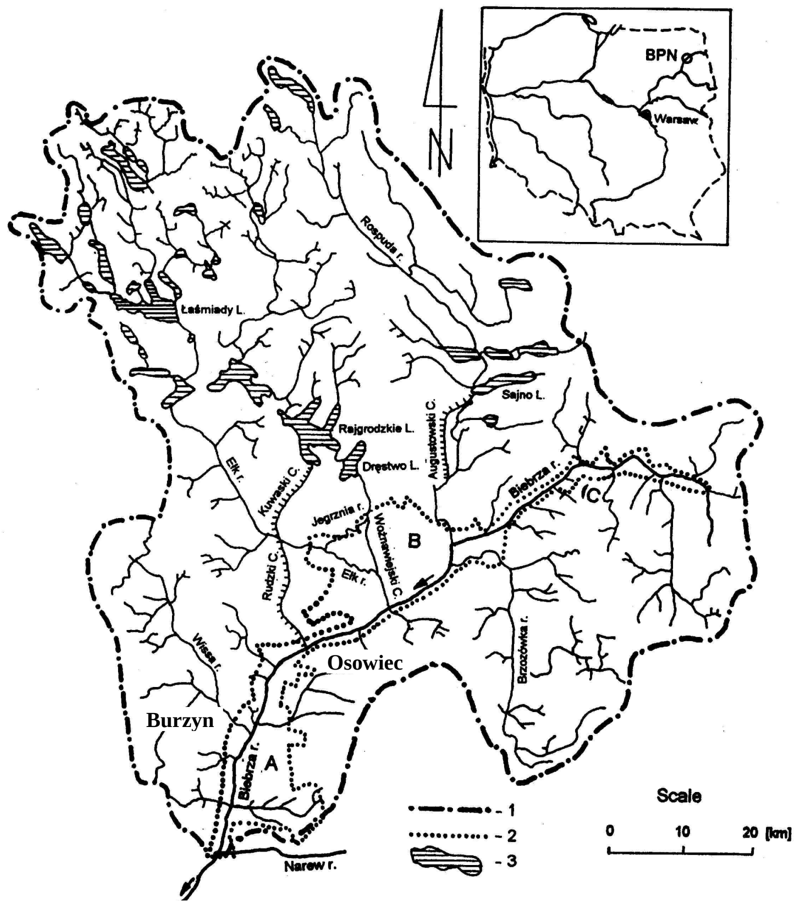

Figure 1. Catchment of the Biebrza River; *1* – catchment border; *2* – borders of the Biebrza National Park; *3* – lakes; *A* – lower basin; *B* – middle basin; *C* – upper basin

Terrestrial non-forest ecosystems are low-growing mire vegetation dominated by sedges and mosses and having a large diversity of grassland too.

Large areas stretching along the Biebrza valley are occupied by communities of *Glyceria maxima*. Further from the river channel, there is a wide zone of communities of *Carex acuta* and next to it a zone dominated by *Carex elata.* In the immersion-emersion zone (sporadic floods) moss sedge communities of patchy structure with *Carex appropinquata* and *Peucedanum palustre* are dominating. Mosses dominate in the emersion zone, not reached by floodwaters.

Human interface led to semi-natural and anthropogenic vegetation types. Ecosystems of anthropogenic character are represented by pastures, croplands and perishing associations.

HYDROGEOLOGICAL CONDITIONS

The valley is formed by eroded channel cutting off loamy–sandy sediments and filled to a depth of 30 – 40 m with sandy formations of moderate permeability. The valley sunken by several dozen meters relative to the surrounding uplands plays a role of the receiver for surface waters from side inflows, subsurface waters from their alluvial stretches and from sandy came covers. The share of waters from direct infiltration of rainfall is remarkable due to the surface area of the valley but it is used almost entirely on transpiration and evapotranspiration. Deep inflows from cut–off intermorainic layers are of greatest importance due to their parameters of hydraulic transmisivity (thickness, hydraulic gradients, and hydraulic conductivity) and due to their temporal stability. This factor makes groundwater level largely independent on external conditions like long droughts, decreased inflows from side streams and decreased water levels in the main channel.

Subsurface waters of a free water table on areas out of the valley occur mainly in shallow alluvia of the side inflows and in outcrops of aquifers among boulder loams and in sandy came formations. Their share in recharging the valley is small but they are mostly used as water resources in most farms (dug wells). In the southern part the watershed runs along dune formations of a large infiltration capacity.

In the lower basin of the Biebrza valley mineral soils occupy only 12.3 % of the area, the remaining area is covered with hydrogenic soils [BANASZUK, 2001].

Two types of hydrologic alimentation was recognised here as far – fluviogenic and soligenic one. Floods (fluviogenic) mostly determine water conditions. On some parts water regime depends on soligenic (groundwater) alimentation from nearby uplands [OKRUSZKO, 1992, WASSEN, 1995]. It seems that the alimentation of the Biebrza valley is more complicated.

HYDROGRAPHIC NETWORK

The Biebrza River within the Lower Basin (Fig. 1) is a 50 – kilometres long stretch from the outlet of the Rudzki Canal down Osowiec, to its outlet to the Narew River. The Biebrza River course is winding and forms many meanders, side streams and old riverbeds, where water appears only during the high water flows. The hydrographic network of the lower Biebrza basin, especially within the valley, underwent marked transformations associated with natural changes in the main river channel and with reclamation works carried out in the valley. On the left Biebrza riverbank single drainage ditches were first (around 1850) made to be extended and completed with the network of additional ditches later (the beginning of 90–ties).

The Biebrza valley has the largest retention capacity among river valleys in Poland. The capacity is comparable with that of large retention reservoirs [OKRUSZKO, 2001]. Such a large retention capacity results from storing water from floods and groundwater in the peat deposits and temporary on the surface of very wide valley (more than 10 km wide). Almost every year the valley is flooded, but in different extension [CHORMANSKI, at. el. 2000].

The hydrological calculation does not indicate basic changes of water levels in the lower Biebrza River (Burzyn quage), which might result from human activity as for example the Narew River regulation, or some other natural or artificial measures. Observed differences of the water level in the period of last 50 years are within the error range [MIODUSZEWSKI, WASSEN, 2000, BYCZKOWSKI, KUBRAK, 1996].

MODELLING

SIMGRO (SIMulation of GROundwater and surface water levels) is a distributed physically-based model that simulates regional transient saturated groundwater flow, unsaturated flow, actual evapotranspiration, sprinkler irrigation, streamflow, groundwater and surface water levels as a response to rainfall, reference evapotranspiration, and groundwater abstraction. To model regional groundwater flow, as in SIMGRO, the system has to be schematised geographically, both horizontally and vertically. The horizontal schematisation allows input of different land uses and soils per subregion, in order to model spatial differences in evapotranspiration and moisture content in the unsaturated zone. For the saturated zone various subsurface layers are considered (Fig. 2). For a comprehensive description of SIMGROW, including all the model parameters readers are referred to Querner (2000) and Slesicka (2001).

In SIMGRO the finite element procedure is applied to approach the flow equation which describes transient groundwater flow in the saturated zone. A transmissivity is allocated to each nodal point to account for the regional hydrogeology. A number of nodal points makes up a subregion as shown in Figure 2. The unsaturated zone is represented by means of two reservoirs, one for the root zone and one for the underlying soil. The calculation procedure is based on a pseudo-steady state approach, using generally time steps of one day. If the equilibrium moisture storage for the root zone is exceeded, the excess water will percolate towards the saturated zone. If the moisture storage is less than the equilibrium moisture storage, then water will flow upwards from the saturated zone (capillary rise). The height of the phreatic surface is calculated from the water balance of the subsoil below the root zone, using a storage coefficient. The equilibrium moisture storage, capillary rise and storage coefficient are required as input data and are given for different depths to the groundwater.

Evapotranspiration is a function of the crop and moisture content in the root zone. The measured values for net precipitation, potential evapotranspiration for a reference crop (grass) and woodland are input data for the model. The potential evapotranspiration for other crops or vegetation types are derived in the model from the values for the reference crop.

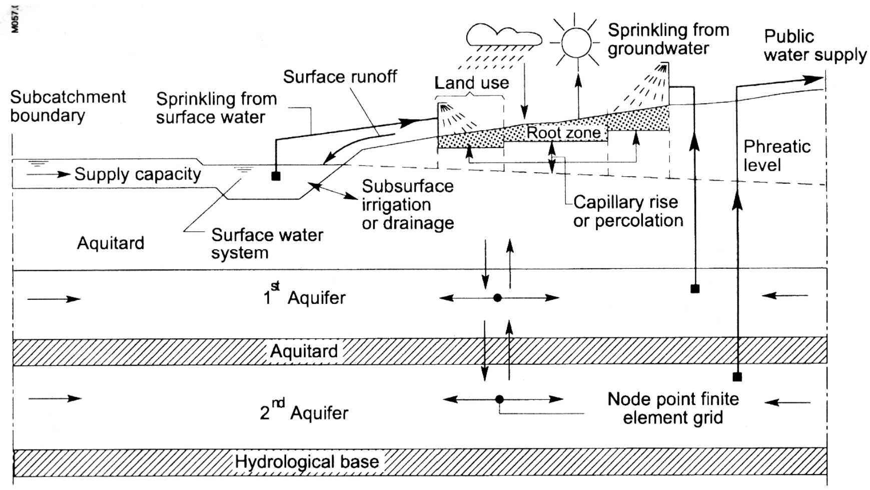

Figure 2. The schematisation of SIMGRO model

The surface water system is often a dense network of water courses. It is not feasible to explicitly account for all these water courses in a regional computer simulation model. The surface water levels in the smaller water courses are important for estimating the amount of drainage or subsurface irrigation, and the water flow in the major water courses are important for the flow routing. Therefore, the surface water system is modelled as a network of reservoirs. The outflow from one reservoir is the incoming flow to the next reservoir, and surface water levels depend on the amount of storage and discharge from a reservoir.

The often dense network of water courses, related to size and density, is important for the interaction between surface water and groundwater. In the model, four drainage subsystems are used to simulate the drainage. The interaction between surface water and groundwater is calculated for each subsystem using a drainage resistance and the difference in level between groundwater and surface water.

The SIMGRO model for Biebrza valley was verified by comparing calculated outflows at the Burzyn gauging installation with the results of field measurements. Verification consisted also in comparing measured and calculated piezometric heights of groundwater of several locations. Additionally, calculated actual evapotranspiration of a meadow was compared with the literature results based on field studies.

THE RESULTS OF SIMGRO MODELLING

The modelling of the groundwater flow makes possible to determine the flow of water below the earth’s surface as set of superimposed groundwater flow–system of various orders connected to a hierarchy of surface water systems. Figure 3 is a result of the programme MICRO–FEM, based on hydraulic heads calculated by the SIMGRO model. The calculations with SIMGRO were done for the present situation, using average values for rainfall, evapotranspiration and river flows for the period 1960 – 1996 [MIODUSZEWSKI, QUERNER, 2002].

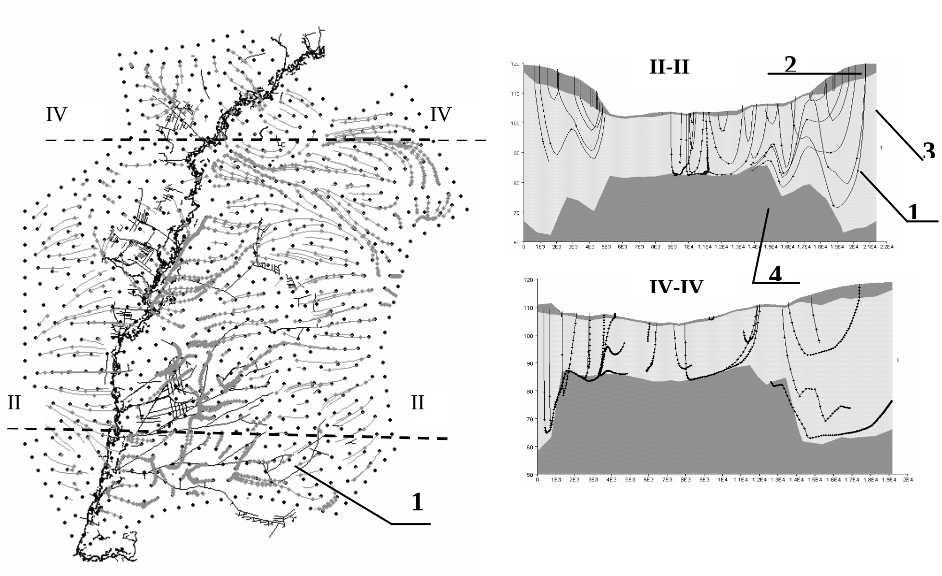

Figure 3. Groundwater system in the Biebrza Lower Basin, 1 – flowlines, 2 – peat, 3 – sand, 4 – clay, I,IV – cross-sectons

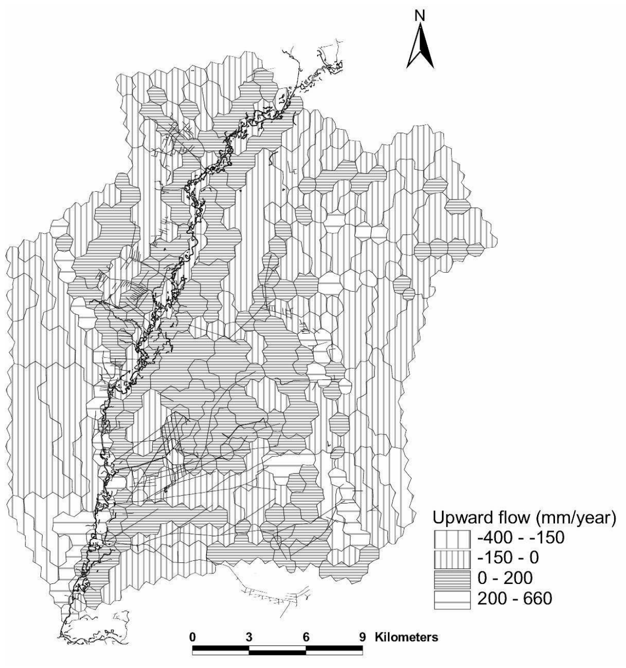

Figure 4. Discharge and recharge areas

model to the underlying sandy aquifer. Figure 4 shows the leakage and seepage. The areas with leakage from the up – lands and the seepage to the Biebrza River can be seen clearly in figure 4.

ZONING OF THE VALLEY

Based on the information from the groundwater modeling experiments, the field observation and analysis of soil types and vegetation assessment, different zones were distinguished, based on the way the water feeds the hydrogenic sites (Fig. 5).

I – a zone immediately adjacent to the river (Fig. 5). It is composed mainly of alluvial (sandy) soils very often used as croplands and forms a narrow belt along the river channel, usually elevated slightly over the surrounding grounds. The zone is under a strong impact of the Biebrza River. Groundwater levels in that areas depend on the river stages. During early spring floodwater feeds this zone as well. Maintaining high water stages in the Biebrza over the whole year is a prerequisite to preserve natural values of this part of the valley.

II – a zone, which mainly covers the central part of the valley and the moisture conditions in the topsoil, depends largely on spring floods. The groundwater supply is a very local patter only. In case of no flood or a flood with a short duration, the ground water level declines in summer leading to unfavourable changes in vegetation. Natural values of this part of the valley can be maintained providing long term flooding. Existing network of man made drainage ditches exerts a negative effect on the water availability. The ditches free from aquatic weeds accelerate the outflow of water in spring after a flood event. In times, when there were no ditches, the water from a flood flew out very slowly. This slow outflow resulted from a high hydraulic roughness of natural vegetation. During growing season after flood period the ground water table depth depends mainly on evapotranspiration and on precipitation.

III – a zone where flood occur very rarely. Some inflow of groundwaters from the upland is observed here. Water often remains several centimetres above the ground surface in this zone – as a result from the inflow of ground waters but also and sometime mainly from the stagnation of spring melt water independent on water stages in the Biebrza River. Low surface slopes and the occurrence of small depressions in the area make the outflow of melt water very slow. There are a few ditches, which might accelerate water outflow from that part of the valley. A sequence of winters with less snow or precipitation may result in unfavourable conditions.

IV – a zone stretching along the base of the upland escarpment. It is a very heterogeneous zone fed mainly by groundwater flowing from the upland or dunes. The area is rain fed as well, usually forested or covered with shrubs with sometimes-visible water seepage. Spring peat is present in some places and groundwater under pressure as well. Main thread for the status of this area is in a decrease of ground water inflow from the upland.

V – a zone of moraine upland and dunes. This is the area consisting of mineral soils. Groundwater is fed by rainfall and at the upland the groundwater levels are often very deep below the soil surface. It is possible to distinguish in the flat area of the valley some small hills very often only several centimetres above to adjacent area. They are sandy hills and are recharge zones similar as the upland zone (moraine). Zone V is of great importance for natural values of the Biebrza valley since water inflow from there is important for water content in zone III and IV and partly also in zone II. Land use in this zone should be in a manner, that it would not restrict the groundwater recharge of the aquifers.

The borders between the different zones are not so sharp as it is shown in the figure 5. Especially the zone III and II are overlapping. During the high flood the area covered by the water from the river is much bigger in comparison to the years with lower river flows during spring. In figure 5 the zone II was marked for high spring water (the high water with 10 % probability of occurrence).

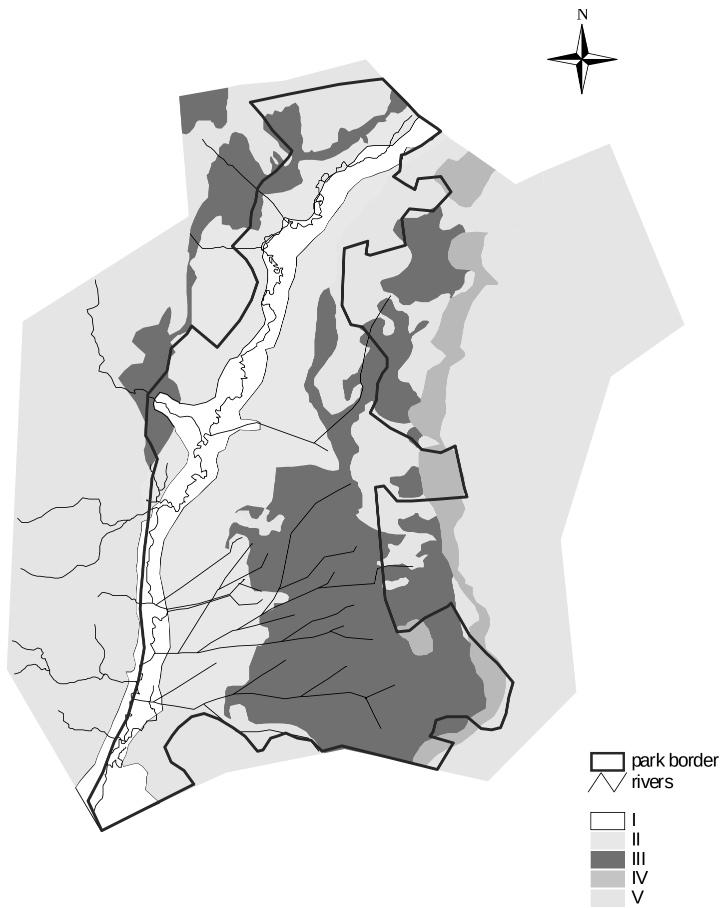

Figure 5. The zones of different recharges of Lower Biebrza Valley (I-V – description see in the text)

DISCUSSION

The hydrological cycle in the Biebrza valley is the overall system of relationships resulting from different processes. At the earth's surface, these processes lead to characteristic landscape patterns such as the network of surface waters, floodplains and brook valleys as well as vegetation and land–use patterns. The flows of both groundwater and surface water contribute to this system of spatial relationships and landscape patterns.

The Biebrza River, together with wide valley creates very complicate and difficult to distinguish water system. There are some signs that the water condition is changing in the river valley. The beginning of peat mineralization is observed. The water conditions of the valley and the moisture of the organic soil – depends on several factors, mostly repeatable and changeable within area. In previous time, hydrological conditions in the valley changed as a result of drainage works carried out in the past and regulation works in the tributaries of the Biebrza River.

This considers water originally comes from the Biebrza River flooding and also waters form snow melting. The analysis of the Burzyn gauge measurements do not indicate any significant changes of the river flow during the last 50 years [MIODUSZEWSKI, WASSEN, 2000, BYCZKOWSKI, KUBRAK, 1996].

It is difficult to estimate whether and until where, if ever, the water supply of the valley by the groundwater was lowered from the upland area. There is significant lack of measurements, which could be the basis for such analysis. Also open is the problem of estimation of evaporation magnitude changeability from valley areas and also from the upland. Could be assumed that the evapotranspiration risen on the terrain of rural usage as a result of the crop growth, while in the valley the cause is the higher soil fertility (atmospheric fall of the nitrogen compounds) and flora changes (the expansion of flora with higher water need; as reed, bushes and forests).

Some differences in flow can be caused by changing the time of flood appearances. It looks that nowadays the flood occur earlier (February), before is in May or June. Anyway this theory should be checked.

measures. The main target should be to preserve the existing hydrological regime and natural water flow dynamics as it was before the construction of the drainage canals and ditches.

Basic actions to maintain optimum water conditions should involve:

CONCLUSIONS

The valley of the Biebrza River is under the highest protection with the National Park status. The preservation of unique wetlands of European importance firstly depends on the high water level maintenance of hydrogenic soils and also large open areas of meadows.

Water condition of the valley area depends on several natural factors, as follow: the magnitude of water flow in the river, very much connected to the regional spring–floods; the capacity and disposal of atmospheric precipitation; groundwater supply from the nearby uplands (moraine) or dunes but also depends on several antrophogenic factors as for instance the land use of lowland and upland; the water quality, existing hydrotechnical infrastructures etc.

Numerical modelling using SIMGRO is a good tool for distinguish the different souces of water filling of river valley.

REFERENCES

BANASZUK H., 2001. *Biebrza Valley. The actual state, natural value and threats.* [in:] *Społeczno–gospodarcze aspekty funkcjonowania Biebrzańskiego Parku Narodowego* (eds. Sadowska–Snarska). Studia Regionalne z. 4. Białystok.pp.9-53 (in Polish with English summary)

BYCZKOWSKI A., KUBRAK J., 1996 The surface water resources of Biebrza river . Zesz. Probl. Post. Nauk Rol. z. 432. pp. 105-126. (in Polish with English summary)

CHORMAŃSKI J., OKRUSZKO T., SKĄPSKI J., MICHAŁOWSKI R., BOROWSKI J., 2000. *Assessment of the flooded area in the Biebrza valley.* [in:] *Some aspects of water management in the valley of Biebrza River*. Eds. W. Mioduszwski, M. Wassen. Falenty: Wydawnictwo IMUZ pp. 101–106.

GUIGUER N., MOLSON J., FRANZ T., FRIND E., 1993. *Flotrans – user guide version 21*. WHS/WCGR.

MIODUSZEWSKI W., WASSEN M. (eds.), 2000. *Some aspects of water management in the valley of Biebrza river*. Falenty Wydawnictwo IMUZ.

MIODUSZEWSKI W., QUERNER E.P (ed.), 2002. *Hydrological system analysis in the valley of Biebrza river*. Falenty Wydawnictwo IMUZ.

OKRUSZKO T. (ed), 2001. *The water protection plan. The management plan of the Biebrza National Park Protection. Warszawa - Osowiec* (not printed).

QUERNER E.P., 2000. *User's manual for groundwater model SIMGRO*. Wageningen, DLO Winand Staring Centre. Draft report.

ŚLESICKA A., 2001. *The influence of hydrografic changed on water resources using the method of mathematical modelling*. Unpublished Ph.D. Tthesis, Falenty: IMUZ.

WASSEN J.M., 1995. *Hydrology, water chemistry and nutrients accumulation in the Biebrza fens and floodplains* (Poland). Wetlands Ecology and Management vol. 3 no 2 p. 125–137. SPB Academic Publishing bv, The Hague. Pp 125-137.