Hydrological model of the Lower Biebrza Basin

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Hydrological model of the Lower Biebrza Basin

Using the model as a management tool

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ABSTRACT

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The main objective of the research is the setup of a groundwater model which can be used for predicting consequences of different land use management options. The constructed Lower Biebrza model is based on the SIMGRO model (SIMulation of GROundwater and surface water levels), a distributed physically-based model that simulates groundwater flow and surface water levels. Two different scenarios were modeled. The first scenario considered the natural vegetation succession of the peatlands as a serious threat. The second scenario considers a man-made approach, and was designed to check which changes in groundwater levels could be expected by blocking the existing drainage system on the Biebrza riverbanks. The study shows that, with regard to the impact on wetland conditions, the first scenario leads to negative changes in simulated groundwater levels while the second scenario leads to positive changes. The research clearly showed that an integrated hydrological approach, by using forecasting methodology, gives results that can be used in the evaluation of water management options. These results can also be the basis of a more comprehensive and profound study that takes into account other factors such as constraints and costs of the different measures and public participation in managing the area.

Keywords: Lower Biebrza Basin, SIMGRO, hydrological model, peatlands, groundwater regime

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Preface

The work presented in this report was carried out in 2004. The first author was on an internship as the final part of the Environmental Resource Management studies at the Vrije Universiteit in Amsterdam. The second author was working for two month at Alterra as a guest researcher from the Institute for Land Reclamation and Grassland Farming (IMUZ) in Falenty, Poland.

During a three-months period the hydrological model of the Lower Biebrza Basin was build. This was only possible to succeed in such a short time because of the great help of a number of persons. Gathering all needed data was an essential part of the research, and in this matter we are grateful to professor Waldemar Mioduszewski from the Institute for Land Reclamation and Grassland Farming (IMUZ) in Falenty, Poland.

Our team work was very motivating by exchanging opinions and setting up mutual conclusions.

Take care of the land,
And it will take care of you.
Take what you need from the land,
But need what you take.

Aboriginal law Source: Howard Wilshire, "Comments on Ecology and Human Life", U.S. Geological Survey, 1993, p. 1.

Summary

The valley of Biebrza River is a unique environmental wetland with mostly peat ecosystems. The area covers 116.000 hectares of peat land shaped by the dynamics of the natural meandering Biebrza River together with the floodplain areas.

The Biebrza National Park was established in 1993 and is under legal protection but outside its borders agricultural activities are under constant development. At present the wetlands are threatened by numerous factors associated with human activities (drainage, ceasing of mowing) as well as natural succession. The area suffers therefore from lower water tables and an increased nutrient input.
Understanding the hydrology gives a proper basis for nature management of the area. Using hydrological modelling it is possible to simulate different situations, which may be taken into serious consideration by stakeholders and environmental scientists who are involved in the decision-making of the Biebrza Basin management policy. The main objective of this research is the setup of a groundwater model which can be used for predicting consequences of different management options.

The Model
The Lower Biebrza model is based on the SIMGRO model (SIMulation of GROundwater and surface water levels), a distributed physically-based model that simulates groundwater flow and surface water levels. After calibration of the model, three different scenarios were modelled. The default scenario ('*Scenario 0*') has been used as the reference scenario to which different management scenarios were compared to. The other two scenarios were modelled to calculate the impact of natural and anthropogenic factors on water conditions.

<u>Scenario 1</u> considers the situation that changes would take place in the land use. The basic assumption was that the valley would be overgrown by forest as the last stage of natural succession. In the model grassland was replaced by forest for the entire valley. In this way the consequences on the groundwater levels could be visualised. Negative impact on the groundwater balance caused by forestation has been confirmed by the results, showing a lowering of the groundwater level in the range of 5 to 15 cm. Due to the increased evapotranspiration by the trees, the level of the groundwater lowered in comparison to the default Scenario 0. Changes in groundwater level directly disturb the ecological balance of the wetland. The appearance of this situation in reality could cause severe changes in the entire area on complex dimensions (flora, fauna, and regional water balance changes). Proper maintenance of the wetland is needed, for example by mowing the grass and grazing cattle, in order to avoid nature succession and preservation of the valuable conditions.

<u>Scenario 2</u> considers a man-made approach, which is the opposite of scenario 1 where the main threat was natural succession. Changes in distribution of surface waters and thus also the groundwater table may affect the water balance of the valley.

In this scenario, the main concern is focused on local changes in the drainage system. This scenario was designed to check which changes in groundwater level could be expected by blocking the existing drainage system on the right bank of Biebrza River. Four ditches out of the dense drainage network were disabled and subsequently the water level changes on regional scale were calculated. The calculated rising of the groundwater table lead to an improvement of the water regime in the order of 5 cm to 25 cm for a few hectares. It is obvious that flora and fauna of the area would benefit from the higher groundwater level.

Conclusions

High water levels in the area of the Biebrza catchment are the major requirement for the future preservation of this unique wetland. That is why it is of great importance to understand the forces that influence changes in the water regime.

To preserve the valuable Biebrza wetlands the moisture conditions of the peat soils is demanding a high groundwater level. These may be obtained by seasonal flooding, which feeds the humified soil and prevents its mineralization. In order to reach this status, proper water management of the area should be conducted.

The best management scenario may be the situation which was present before the construction of the drainage system. However this scenario is not realistic due to several limitations as for example lacking financial resources, time constraints, and ongoing discussions about the desired management plan. But some measures should be promoted such as:

- Priority to preserve the present hydrological network
- Pro-active management of the peat lands in order to avoid natural succession
- Promotion of extensive agriculture focused on bio-products, which could diminish the nitrogen load into the water system

This research may be seen as a support tool for decision-makers who are responsible for management plans of the Biebrza valley. One of the main results of this research is the model itself, as a tool for finding the best possible management options both from a natural and agricultural point of view. The research clearly showed that an integrated hydrological approach, by using forecasting methodology, gives results that can be used in the evaluation of the effects of water management possibilities. These results can also be the basis of a more comprehensive and profound study that takes into account other factors such as constraints and costs of the different measures and public participation in managing the area.

1 Introduction

1.1 Background information

The role which peat lands play in the nature is widely recognised. Peat lands are important part of the ecosystem for nature and its conservation. The types of vegetation and a large numbers of animals, which can be recognised on the peat land area is a good evidence of its rich biodiversity.

Biebrza Valley, situated in northeast Poland, is a unique environmental wetland with mostly peat ecosystems. The area covers 116.000 hectares of peat land shaped by the dynamics, natural meandering Biebrza River together with floodplain areas. Biebrza River, traditionally called Bobra by the locals, is one of the beautiful lowland rivers in Poland. It is a home to a great variety of rare species of animals, with a large number of birds and plant communities placed on the IUCN[1] Red List of endangered species. The size of the area together with its natural characteristics make the Biebrza basin a good reference area for a large number of wetlands and transformed river basins of Europe (Wassen et al. 1990). Due to its unique nature, in 1993 the Biebrza National Park was established. The Park with an area of 59223 hectares is the biggest in Poland (Bokdam et al., 2002).

Since Biebrza peat lands include minerotrophic fens fed by up welling seepage and ombrotrophic rain-fed bogs (Bokdam et al., 2002) the changes in water balance may disturb the biodiversity. Hydrology of the area is the major factor determining the status of soils, flora and fauna in various extends. At present, the wetlands are threatened by numerous factors associated with human activity (drainage) as well as natural succession. Major changes in the groundwater balance may cause unpredictable and irreversible changes in such a sensitive ecosystem. Surface and groundwater conditions, its quality and quantity, are responsible for the status of peat lands. One of the dangers of the Biebrza National Park is an over drying of the soil, caused by drainage works carried out in the past. That is why a thorough understanding of the hydrology should give the basis for proper management of the area.

This study is focused on the valley of Biebrza river (the Lower Basin). The valley of the river Biebrza, situated in the Northeast of Poland (22°30′ - 23°60′E and 53°30′ - 53°75′, see also figure 2.1) is one of the last extensive undrained valley mires in Central Europe (Succow & Jescheke, 1986 in Wassen, 1990). The Biebrza basin is subdivided by morphological features into three parts defined as the Upper, Middle and Lower Basin (Okruszko, 1973 in Wassen, 1990). This research focuses on the Lower Basin mostly.

[1] International Union for Conservation of Nature and Natural Resources

Since the last century, 80% of the Middle Basin has been drained, causing drying of the peat soil (Wassen, 1990). The Lower and Upper Biebrza Basin has been much less disturbed (Liwski, 1984 in Wassen, 1990). However a small part of the Lower Biebrza Basin was covered by the drainage-irrigation system, causing local changes in the level of groundwater.
It is clear that man-made changes in hydrological networks for agricultural purposes led to local changes in the water regime. The important question is how far the changes of hydrological networks could affect the water balance of the area and in which extend the proper management of the peat land can payback, leading to a desired hydrological situation? Those questions are too complex to be answered by conducting one research due to the large number of variables related to these physical-environmental phenomena. Anyway it is important to discover and explore new possibilities from a technical point of view (complexity of software, the use of Arcview, etc.) and its application for predicting possible changes (creation of possible scenarios) related to the hydrology of the area. .
Together with predicting possible changes in ecosystems caused by both the engineering works (changes in drainage-irrigation system) and the nature itself (natural succession) this research will evaluate on two scenarios, where both natural succession and man-made changes can cause positive or negative impact to the water balance of the Lower Biebrza catchment.

1.2 Description of problems and research objectives

The area of Biebrza National Park is under legal protection but outside its borders agricultural activities are under constant development. At present the wetlands are threatened by numerous factors associated with human activity (drainage, ceasing of mowing) as well as natural succession. Understanding the hydrology gives a proper basis for nature management in the area. The area is under the pressure of lowering water table and increase of nutrient input. Quality and quantity of water is of major importance since the destruction and negative impact can suddenly appear and the consequences could be very difficult to undo.

Several studies that were conducted were focused on issues which depended on its present necessity. For instance sudden events, such as fire of peat soils, caused the necessity of scientific investigation and judgement of human impact on the natural resources. Some examples below indicate important issues and problems, which were the motors for further research:

- Flood precaution by using surface water models
- Recognition of endanger species by using vegetation models
- Recognition of vegetation diversity by ecological models
- Impact of human activity on the area of river catchment; relation between natural environment and human activity (studies on the impact of intensified agriculture and positive feedback to implement old-fashion agriculture practise of maintenance of the area)

This research mainly focuses on the functioning of hydrological systems in the Lower Biebrza Basin. The main priority is the setup of a groundwater model for the purpose of defining changes due to different land use management options.

Due to the preservation of valuable wetlands of the Biebrza river catchment, proper water management policy has to be carried out. Any changes in quality and quantity of the regional water system can cause irreversible impact. To predict unwanted changes by building the hydrological model was one of the major objectives. Another important objective is creating different management scenarios by using the model as management tool in order to predict changes in water regime of the research area.

1.3 Methodology

At the beginning of the research certain steps were done as a preparation. The steps are as follows:

Literature review
Become acquainted to the research area and describe main issues such as:
- Hydrological conditions (surface and groundwater)
- Description and the role of peat lands in the research area

Introduction meetings
During the meetings with the team members (persons connected to the previous projects on Biebrza catchment and others who are interested), the objectives and goals of the research were specified and precisely formulated in order to meet them by conducting research within a certain time frame. The following issues were discussed during the meetings:
- Formulation of goals and objectives
- Selected of study area
- Reviewing of available data

Data collection and preparation
To collect all data needed for the purpose of building the model all available sources were used:
- Digital data
- Existing maps in Arcview
- Topographic maps
- Personal interviews

Estimation of data, which has to be collected further on
Estimation of missing data, further assumptions and filling in of gaps, in order to make data more complete.
The detailed list of data which were used as an input files to the model will be point out in the section considering model building.

Used model
SIMGRO model (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, stream flow, 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. AlterrAqua is an Arcview GIS application, developed around the SIMGRO model.

Process of model set up
The general steps leading to the model set up are as follows:
Preparation of the input files strictly required by the model 'frames'

Model running
- Calibration of the model based on measured data (field measurements)
- Verification and final adjustments of created model

After the setup of the model, the next part of the project was focused on the management, creation and selection of several scenarios according to the goals and assumptions which were specified at the beginning of the research:
- Running different scenarios
- Visualisation of results
- Evaluation of results
- Conclusion and further recommendations
- Gaps and omissions as a lesson for the future

In figure 1.1 (flowchart) the activities, which were conducted during the research, in chronological order have been presented. The flowchart provides the structure of the research. The creation of main ideas, combining knowledge with accessible tools (equipment, software) and data accessibility (sources of data) as well as the management approach have been displayed.

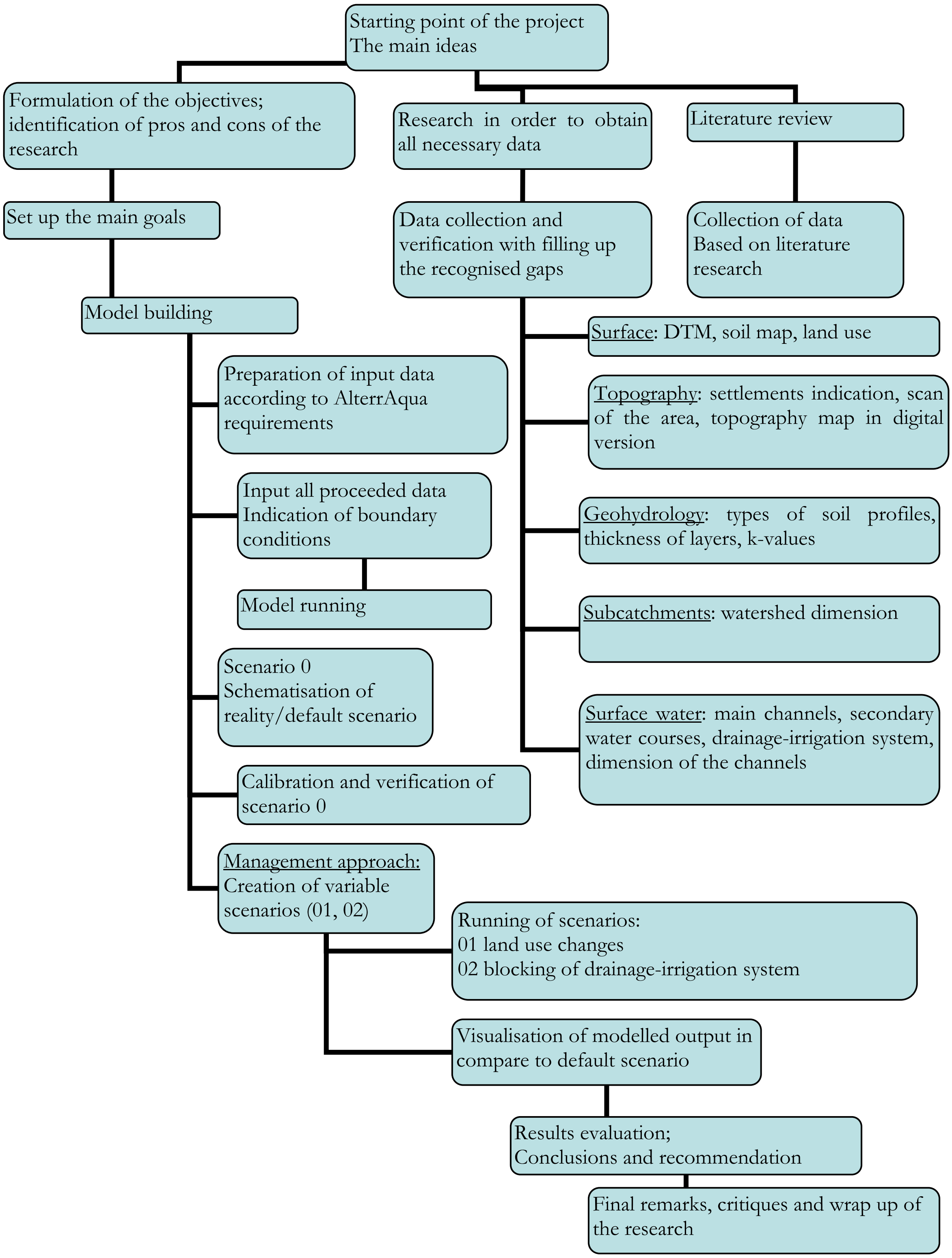


Figure 1.1. Flowchart of activities

2 Description of the research area

The study focuses on the area of the Biebrza Basin, which is located in the Northeast part of Poland (figure 2.1). Due to the well-preserved nature the area is known as the “Green Lungs” of Poland. The valley of the river Biebrza in north-eastern Poland is considered to be one of the last extensive undrained valley mires in Central Europe (Wassen 1990).

Figure 2.1 Location of the Biebrza basin in Poland (UNEP, 1997)

2.1 Biebrza River Basin

The Biebrza River has a length of 165 km, and is located in sloping moraine landscape surrounded by peat fens and meadows. The basin of the river is one of the most valuable wetland areas in Europe. The area covers 116,000 hectares of almost untouched peat land shaped by the dynamics of the unique, naturally meandering rivers together with floodplain areas. It is home to a great variety of rare and endangered species of animals, 157 species of birds, 18 different species of orchids and approximately 500 elks living along the Biebrza River (Bokdam et al., 2002). The size of the area together with its natural characteristics make the Biebrza drainage basins a perfect reference area for a large number of transformed river valleys and freshwater wetland areas of Europe (Wassen et al. 1990). The natural character of the Biebrza wetlands is reflecting the peat-forming plant communities in a very regular pattern. The importance of the area is widely recognised. To protect the most valuable parts of the Biebrza valley in 1994 the national park was established.

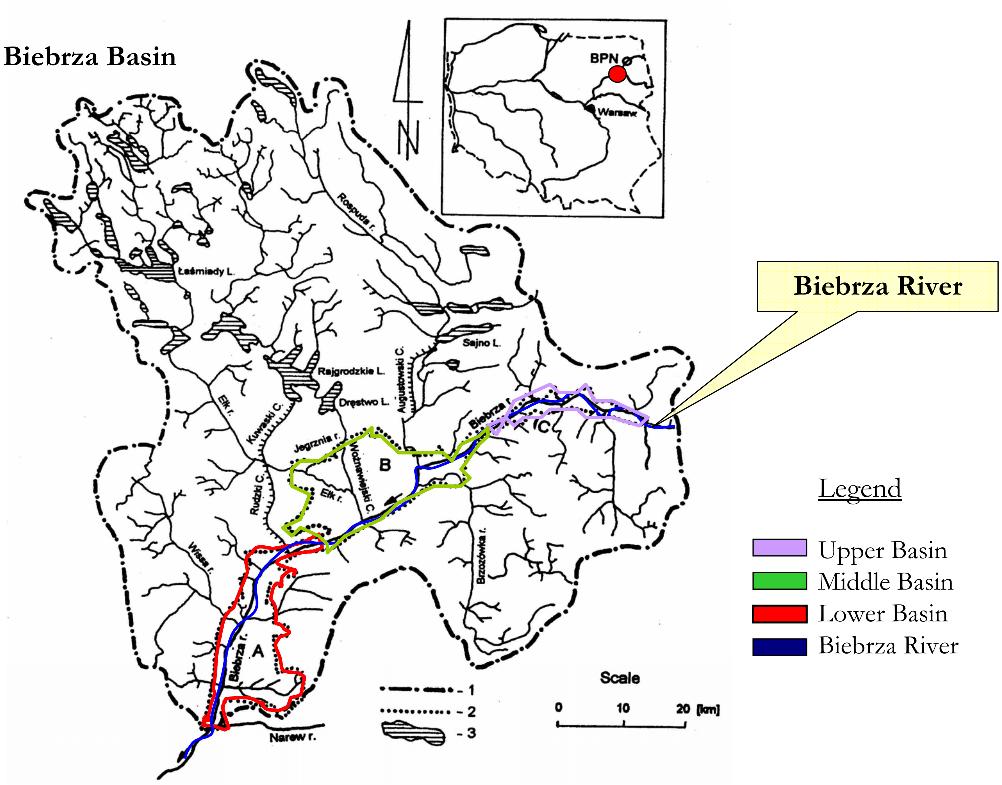


Figure 2.2 Morphological division of the catchment into upper, middle and lower basin (Mioduszewski et al, 2002)

The national park is situated along the Biebrza River and covers some 600 km^2, making it the largest national park in Poland. Within the national park land use is predominantly grassland for meadows, pasture and partial woodland. The discharge of the river differs during the year. In summer the discharge is about 10–20 m^3·s^{-1}, but in early spring when the snow melts, the discharge increases to more than 100 m^3·s^{-1} (Querner et al., 2003). Almost every year during springtime, due to snow melting the valley is flooded.

The part of the Biebrza river within the Lower Basin, that is subject to this research, has a length of about 50 km from the end of the Rudzki Canal at Osowiec, to its outlet in the Narew river (figure 2.2). The main river course forms many meanders, side streams and old riverbeds, where water appears only during high flow stages (Querner et al., 2003).

2.2 Maintenance of Lower Basin

In the Middle Basin drainage works in the 19th century have resulted in the drying out of peat soil, enhanced mineralization of organic matter and the subsequent deterioration of the vegetation (Wassen et al., 1990). The changes affected also the Lower Basin. Over the last two centuries, the main channel of the Biebrza River was not greatly affected by man-made changes. However, the pattern of smaller streams in the Lower Basin registered substantial changes (Mioduszewski, 1999). Due to specific hydrological conditions of the valley (importance of water table for the preservation of valuable peat lands) changes in hydrology need to be evaluated and underlined in order to estimate the best management scenarios for the region. The dense network of small tributaries of old riverbeds was subsequently replaced by a number of straight ditches which caused a marked transformation of the valley. The role of the ditches network was draining the valley more effectively for more intensive agricultural use (such as pastries). At present the ditches are no longer under maintenance and increasingly overgrown by vegetation and silting up.
The modelling area involved the Lower Biebrza valley and adjacent uplands. The natural character of the Biebrza peatlands is reflected in a very regular pattern of peat forming plant communities which run over the length and width of the valley (Wassen, 1990). The valley is bordered by large moraines (figure 2.3). The altitude of the entire valley ranges from about 100 to 130 meter above sea level, with a maximum of 160 meters (Byczkowski & Kicinski, 1984 in Wassen, 1990).

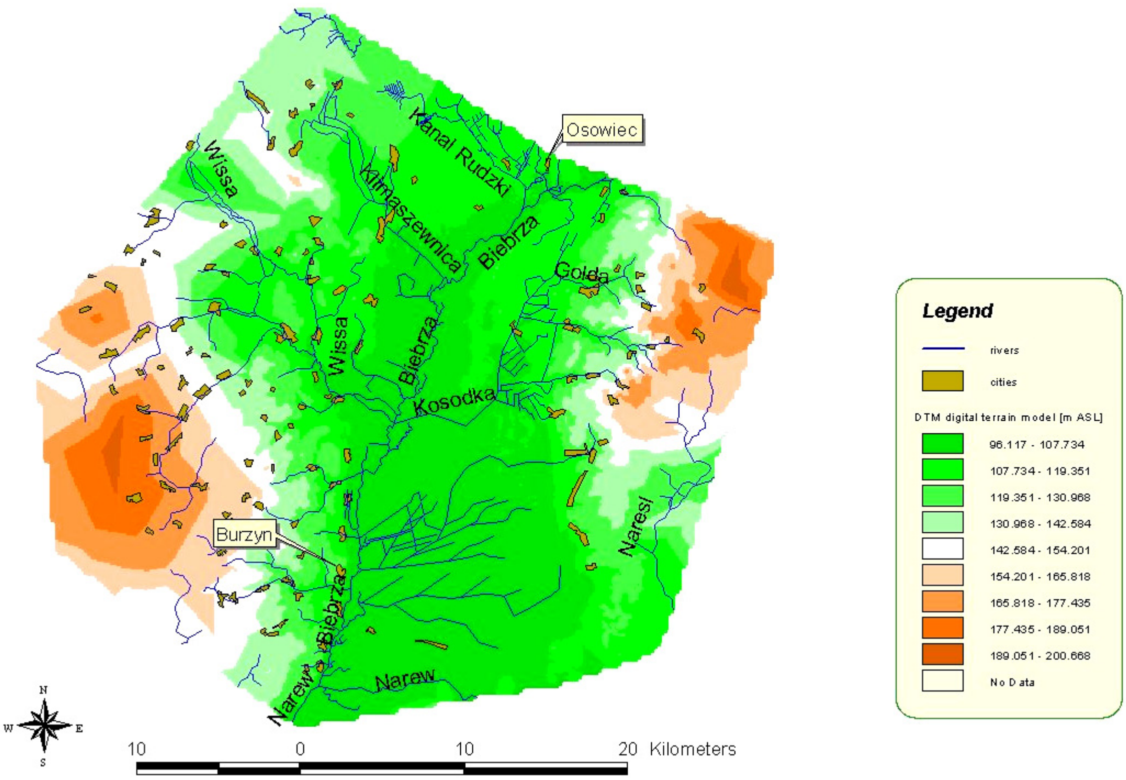


Figure 2.3 Topography map of the research area

The mean rainfall is 583 mm, of which 244 mm falls in the wet summers (Wassen, 1990). Mean annual temperature is rather low (6.8°C) and the growing season is quite short, about 200 days (Kossowska-Cezak, 1984 in Wassen, 1990).

2.3 Biebrza and Narew

The south part of the model area needs to be highlighted because of the specific regional water regime. The two main rivers Biebrza and Narew (figure 2.2, 2.3) come together and continue as the Narew river stream. The outflow point from the Lower Biebrza Basin Model (LBBM) is situated down stream of the Biebrza-Narew confluence. It means that these specific situations can cause differences in water tables (surface and ground) and can change and influence regional hydrological conditions in this area.

Not many researches were done on the terrain where the Biebrza river joins the Narew river. As far as the literature survey indicates, a research connected to afore mentioned issue was conducted by IMUZ[2] Falenty. The main goal of this research (by IMUZ) was to assess the impact of the regulation of the Narew river on water levels in the mouth section of the Biebrza river (Mioduszewski, 1999). The research evaluates different causes that led to changes in the water regime in this particular terrain. Over many years the transformation in vegetation communities caused by man-made changes gave an indication that changes in the water tables is caused by improper maintenance of the area. However according to this research the network of ditches, which was created over 150 years ago, does not really play a main role in management of water resources due to the lack of maintenance (which in resulted succession of vegetation).

Another change in the hydrographical network was caused by the regulation of the Narew river, which was carried out in 1969-1970 (Mioduszewski, 1999). The project of regulation of the Narew River started at the Narew-Biebrza confluence and continued upstream Narew. The purpose of this work was to intensification of agriculture in the Narew valley, and the construction of land improvement drainage-irrigation systems. The Narew river meandered widely in the past between its confluence with the Biebrza and further upstream (Mioduszewski, 1999). The magnitude of the changes that were done during the regulation work of Narew river, is exemplified by the shortening of a 7360 meters stretch of the meandering river to 3000 meters. The river channel was straitened and was made with a regular trapezoidal cross-section. The result was a decrease of the water level in the river.

One of the main conclusions of the IMUZ research was as follows (Mioduszewski, 1999, p.69): regulation of the Narew River in the section between its confluence with Biebrza river and upstream did not lead to the lowering of the water level at Biebrza river.

[2] Institute for Land Reclamation and Grassland Farming (Falenty, Poland).

3 Schematisation and hydrological modelling

3.1 Background information

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, stream flow, 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.

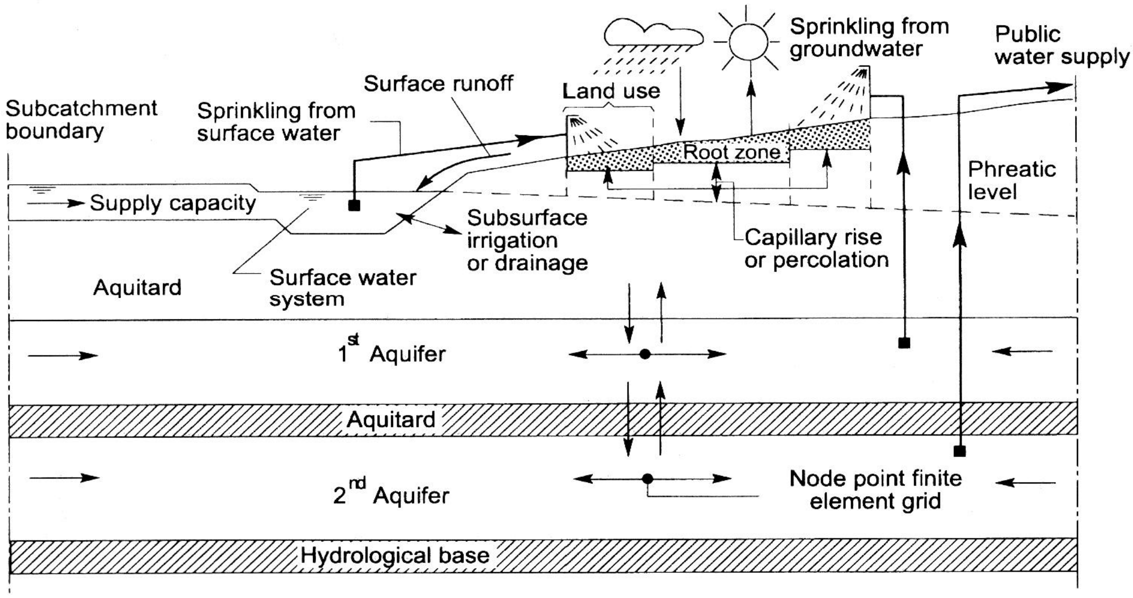


Figure 3.1 Schematisation of water flow in the SIMGRO model (Querner, 1988)

The horizontal schematisation allows input of different land uses and soil types, in order to model spatial differences in evapotranspiration and moisture content in the unsaturated zone. For the saturated zone various subsurface layers are considered (figure 3.1). For a comprehensive description of SIMGRO, including all model parameters readers are referred to Querner (1988, 1997) and Dik, Veldhuizen (2003).

In SIMGRO the finite element procedure is applied to approach the flow equation that describes transient groundwater flow in the saturated zone. A transmissivity is allocated to each nodal point to account for the regional hydrogeology. The unsaturated zone is represented by means of two reservoirs, one for the root zone and one for the underlying soil (figure 3.1). 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 vegetation types are derived in the model from the values for the reference crop (Querner, 2003).

The surface water system is a dense network of watercourses. The surface water levels in the smaller watercourses are important for estimating the amount of drainage or subsurface irrigation, and the water flow in the major watercourses 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 dense network of watercourses, related to size and density, is important for the interaction between surface water and groundwater. 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 (Querner, 2003).
In the SIMGRO model snow accumulation has been accounted for. The assumption is made that snow accumulation and melting is related to the daily average temperature. When the temperature is smaller than zero Celsius, snow accumulates. For temperature between zero and one degree Celsius, both precipitation and snow melting occurs: it is assumed that during day time precipitation occurs and during night time the snow accumulates (50/50%). When temperature is higher than one degree Celsius, the snow melts with a rate of 3 mm/day per degree.

3.1.1 User interface AlterrAqua

AlterrAqua is a user interface in ArcView, developed around the SIMGRO model (Vries, 2003). The purpose of this application is to make the SIMGRO regional groundwater model more user-friendly and easy accessible. The development of this user interface started when several water boards in the Netherlands faced the problem of high waters due to extreme rainfall and high surface water levels in the rivers (Dik, 2002; 2003). The application enables the use of SIMGRO within the GIS environment of ArcView. The power of the instrument is its link to existing digital geographical information (soil maps, land use maps, watercourses, etc.). SIMGRO inputs are generated in separate AlterrAqua modules. For more information and detailed description of SIMGRO input and output files please refer to Dik (2002).
Because AlterrAqua was developed according to Dutch environmental conditions (for example weather conditions), the default values used in standard data files and look up tables initially contain Dutch standard values. Therefore during the research

changes were made in the scripts to adapt the model to Polish environmental conditions.

3.1.2 Good modelling practice

Proper and reliable use of models is necessary to obtain realistic results and further on for the proper water management. Due to the many choices that had to be made during the process of model building, errors are easily made. Such errors possibly could be done by for example poor calibration or application of parameters with unreal values. The application of good modelling practice (GMP) is applied when the process of the modelling follows several steps. If steps are not performed due to different circumstances (lack of data, time constrains) it is possible that input and also output data may be uncertain. Steps of good modelling practice could be as follows:

- Start survey
- Set up project
- Set up model
- Analyse model
- Use model
- Interpret results
- Report and archive

In this research, due to time constrains as well as partial lack of data, some of the steps of GMP were omitted.
In my research various processes that influenced the quality of the research outcomes are worth mentioning. During modelling the expert judgement is crucial for successful results. The biggest effort was made setting up the model, to have variables include schematisation in all dimensions, data collection and implementation of building possible scenarios. In order to avoid many mistakes, the SIMGRO input module checked input variables in consistency (Dik & Veldhuizen, 2003). The checks include restrictions in the presence of required input files and checks inside the tables. Several mistakes were detected during the running of the model, and were corrected to obtain the best results. Another important step was to perform a sensitivity analysis. This step showed which parameters substantially affected the modelling results and which ones hardly did. More details on this subject can be found in paragraph 3.5. The results of the sensitivity analysis were useful for model calibration purposes.

3.2 Input data required for the model

3.2.1 Specification

The physically based groundwater and surface water model SIMGRO was used to gain insight in the regional groundwater patterns and simulate the effects of

measures. To obtain a proper management tool, which is the model itself, all information related to hydrological conditions was important.
Input data needed to build the model was prepared mainly in ArcView. It required precise strict data input files specified and described in the AlterrAqua user guide. Detailed descriptions of each required input file can be found in *SIMGO Input and Output* manual.

In table 3.1, general information on the input data, which were prepared in ArcView in order to build the model, is displayed. Data was collected from different sources, and often needed aggregation.

Table 3.1 Input data for building the model

Data	Format input data (ArcView)	General information
1. Model boundary	Shape file (**polygon**)	After discussion with project members, the model area was specified considering mainly river catchment (subcatchments)
2. Ground level (DTM)	Grid	Digital Terrain Model for major part of the terrain was already prepared, the missing part prepared during data processing
3. Surface water courses	Shape file	Specification of riverbed classes; dimensions of watercourses.
4. Hydrogeology	Grid	Types of soils and thickness of layers.
5. Land use	Grid	Types of land use on the terrain
6. Soil map	Shape file (polygon)	Types of upper soil layer

3.2.2 Preparation of the input data

The first step of input data preparation is making a decision about the size of the model area. This decision on the model boundary depends on two main factors:

- What area is of special importance and why: rich biodiversity and naturally preserved peatlands area with a large terrain under national protection (part of the Biebrza National Park) due to a natural water regime (with old river beds, natural meanders, wetlands). The terrain consists of a part of the Lower Biebrza catchment and is extended to include a large part of the West upland including Wissa river (one of the inflow rivers to the area) and East upland with tributaries of Biebrza river (see figure 2.3 and figure 3.2).
- Accessibility to required data: digital versions of subcatchments and surface water, possible access to measured data from piezometers (groundwater measurement points) to be able to calibrate and verify the model.

The most important data sets that were used to build the model are discussed below.

Digital Terrain Model (Ground level)
Digital Terrain Model (DTM) for the major parts of the terrain had already been prepared, missing parts were completed using topography maps, by projecting

numbers of chosen coordinated points (X,Y,Z) in a way to cover the entire area. The existing and projected DTM (during the research) were joined and major corrections of the completed DTM were made.

Surface water
Surface water input data consists of information on the main river streams, secondary water courses and drainage systems. For the purpose of the model the dimensions of water source had to be given, such as bottom width, left and right side slope of the river bed (river bed dimension) as well as invert down and upstream. All needed data was gathered from fieldwork measurements (the most reliable), topography maps, literature research and expert judgement.

Hydrogeology
Type of soils, the specification of hydrological conductivity and a definition of the number of layers (and its thickness) had to be presented. Detailed data of geology was available on the terrain of Biebrza National Park (BNP) by field measurements conducted during earlier works. The rest of the area was estimated based on literature records and soil maps.

Land use
The land use on the terrain outside the BNP was prepared based on topography maps and literature records. The area within the borders of BNP consists of detailed fitological information, which could be used partly as a indication of land use.

Soil map
The first layer of the geological data was used as a basis to prepare the required map of soil types of the area. The gaps were assumed based on literature and earlier researches.

Additional data
The schematisation of the natural processes mostly is very difficult. To be able to present the reality in the most natural way, meteorological data were needed.
Meteorological data came from the Bialystok branch of the Institute of Meteorology and Water Management Observatory station in Experimental Farm placed in Biebrza valley as the IMUZ measurement station. The data covers daily records of:

- Precipitation (mm)
- Temperature of air (ºC)
- Evapotranspiration

For the purpose of model verification, additional data were gathered on:

- Daily discharges of surface water measured in two gauge stations (Burzyn, Wissa).
- Daily groundwater level measured in 5 piezometers (deep and shallow)

3.3 Building the model

3.3.1 Model area

The model area covers the main part of the Lower Biebrza Valley (about 80%) and a major part of neighbouring upland (figure 3.2). The choice of the border on all sides was based on the dimensions and shape of watershed.
On the south side the watershed divided the Biebrza valley from the Narew valley. This area is of special importance due to the fact that it is the meeting point of two important rivers, Biebrza and Narew. The west border of the area doesn't cover the entire west Lower Biebrza Basin, because the area was to large and of relatively limited importance to the management scenarios. Both the east and west boundary of the area is bordered by upland.

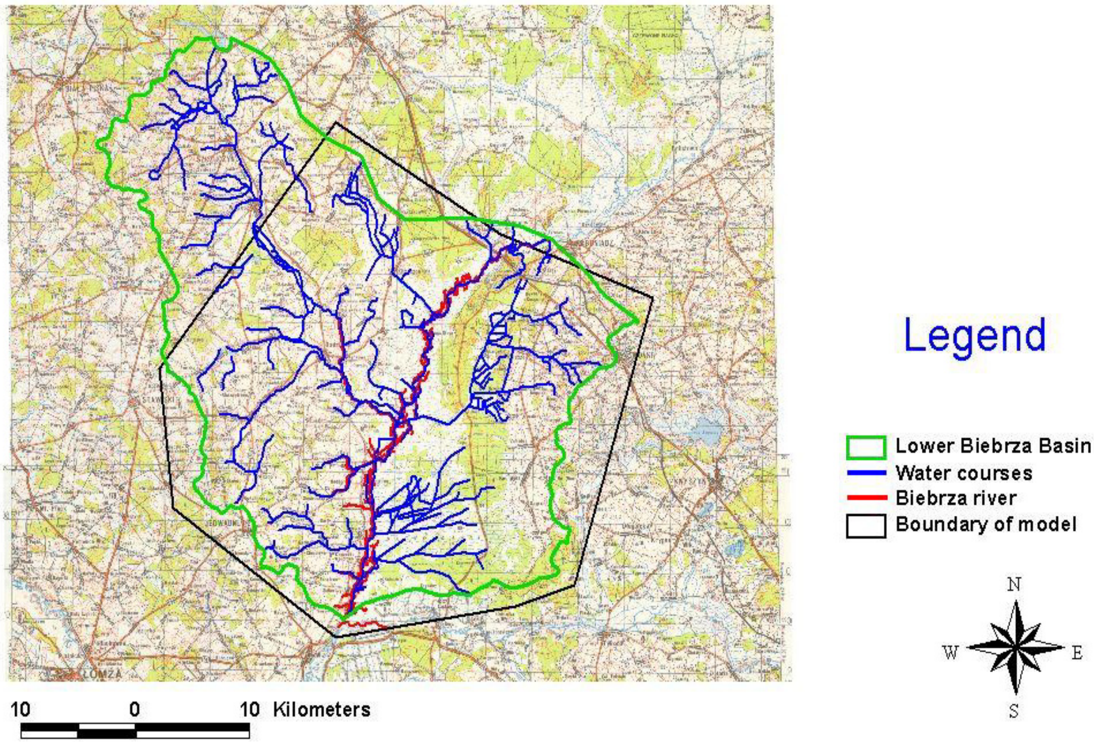


Figure 3.2 Model of the area

The modelling area covers approximately 133.764 ha and consists of the main part of the Lower Biebrza Basin (LBB) together with uplands and parts of the Narew Valley. The main stream of Biebrza river flows from northeast to south.
On the south side the Narew river joins the Biebrza stream and from this point Biebrza becomes a part of Narew River. The area where the two main lowland rivers meet together is of large importance. Narew River is different in comparison to Biebrza, with different dimensions of riverbed and discharges. One of the main tributaries of Biebrza river is the Wissa river, situated in the north-western part of the Lower Biebrza Basin. More detailed information will be presented in paragraph 3.3.3 where an overview of the surface water network will be displayed.

3.3.2 Input data schematisation

To carry out the calculations it is necessary to firstly prepare adequate data considering the hydrogeological conditions. As mentioned above, information about the properties and conditions of the saturated and unsaturated zones, meteorological observation and hydrological measurements had to be gathered.
The entire model area is covered by 7854 nodal points (nodes) with a mean distance of 400 m between them, which creates a network of finite elements of 15 344 triangular elements. Each node is determined by geographic X Y coordinates and terrain level dimension Z.

3.3.2.1 Schematisation of hydrogeological conditions

Based on field measurements, digital data from the terrain of BNP and literature research the geological conditions were defined. It was assumed that there are two hydrogeological layers of varying thickness, aquitard and aquifer layers placed on impermeable strata.

The upper layer is mostly composed of shallow and medium peat and sandy alluvia (Mioduszewski, 2000), and its thickness is ranges from 10 cm at the shallow layer up till 2.5 meters (figure 3.3). On uplands the first layer is shallow (10 cm) and gradually becomes thicker down to the valley direction where it is mostly about 50 cm thick. The thickness of alluvia along the Biebrza river varies from 50 cm and 75 cm. The thickest part of first layer appears on the south-eastern part of the modelled area, where a dense network of drainage systems exists. On this area the layers thickness varies between 150 cm and 250 cm.
Hydraulic conductivity (k-value) of the first layer varies in general from the lowest 0.002 $m \cdot d^{-1}$ up till 0.1 $m \cdot d^{-1}$ (figure 3.4). On the terrain of the uplands the k-value mostly is 0.1 $m \cdot d^{-1}$ and gradually increases towards the valley where it has a value of 0.066 $m \cdot d^{-1}$ and 0.075 $m \cdot d^{-1}$. At the north-eastern part of the area the beginning of the lower catchment k-value ranges between 0.0054 $m \cdot d^{-1}$ and 0.016 $m \cdot d^{-1}$. Along the Biebrza river the k-value is the smallest (ranging from 0.002 to 0.004 $m \cdot d^{-1}$). The water movement in this layer is assumed to have a horizontal flow.

The underlying layer represent sandy formations, with thickness which differs from 2000 cm on the valley terrain to 3500 cm on the west upland and small parts of the valley. The thickest layer is situated on the east upland and is 5000 cm thick.
Hydraulic conductivity ranges between 6 $m \cdot d^{-1}$ (almost on the entire terrain of the model) and 10 $m \cdot d^{-1}$ (upstream of the Biebrza river). The water movement in this layer is assumed to have a vertical flow. The sandy layer is placed on an impermeable stratum.

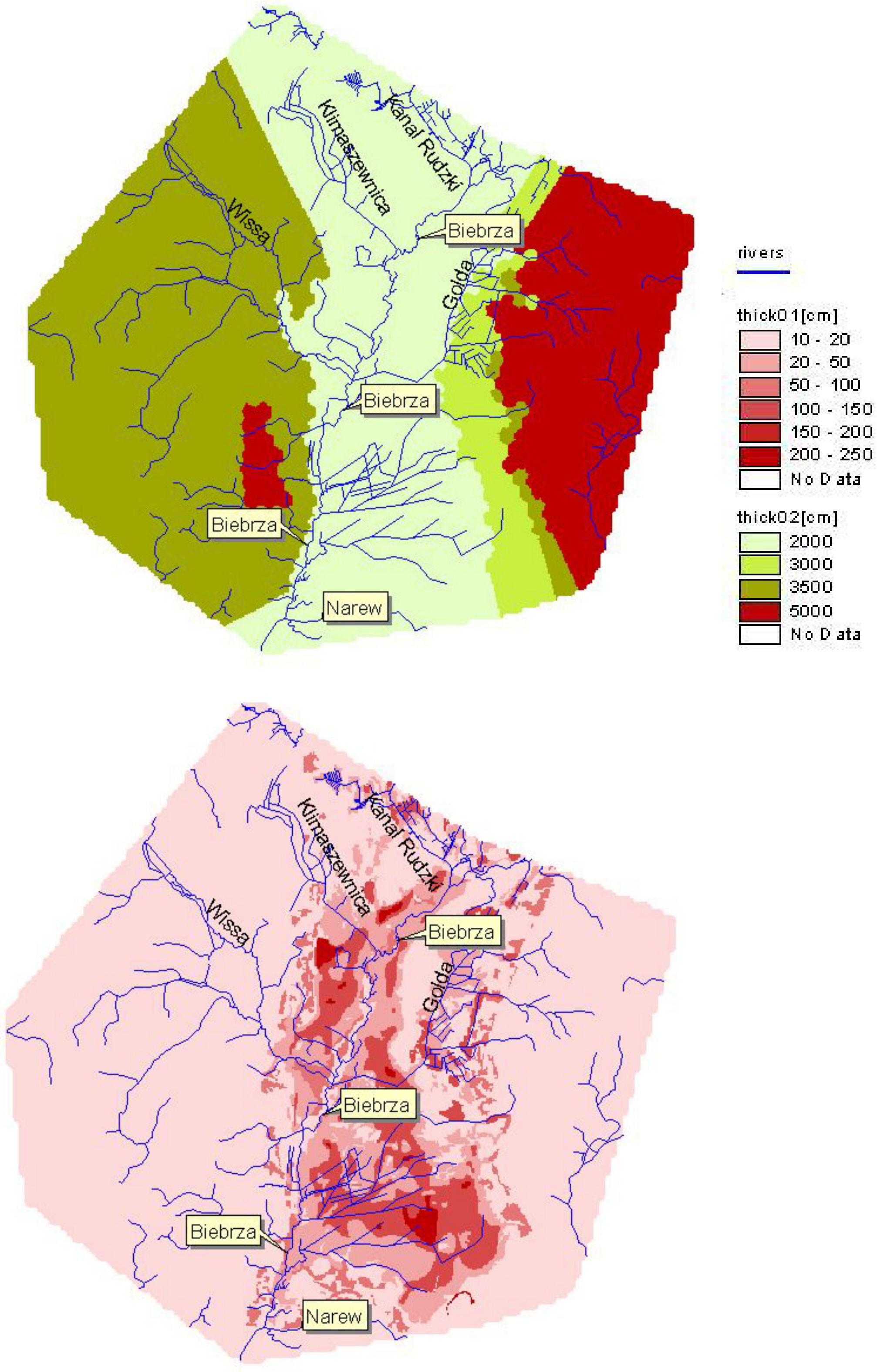


Figure 3.3 Thickness of first and second layer

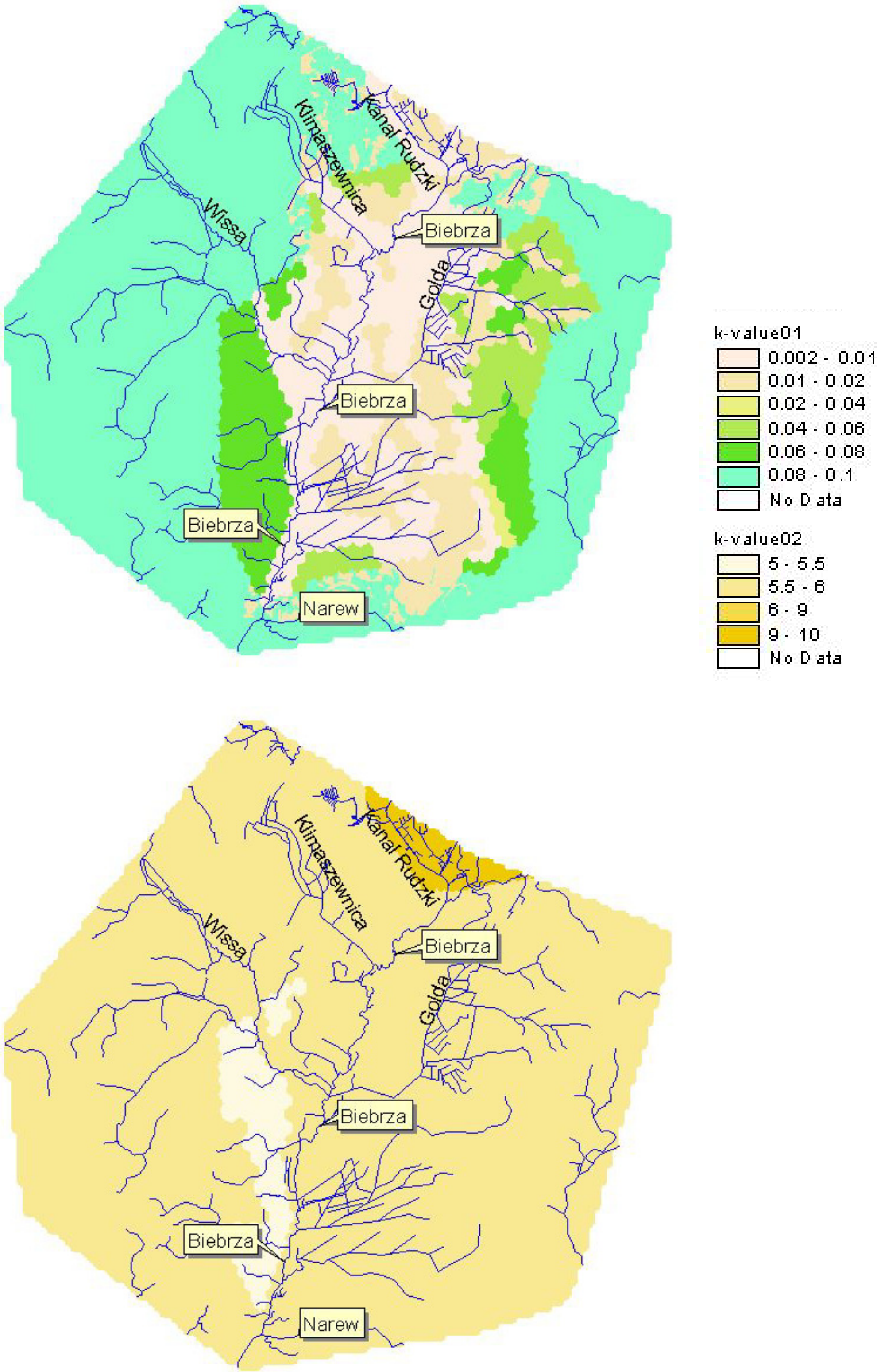


Figure 3.4 K-value of first and second layer

3.3.2.2 Soil types

To model water conditions in the unsaturated zone the types of soils were determined. Types of soils together with characteristic parameters (k-values) were defined according to original classifications. Figure 3.5 presents types of soils, which were originally defined and recognised according to Polish standards. On the area of BNP detailed data of soil types was available, which is included in the figure below. The area outside the BNP borders was assumed to be sandy soil, since no detailed information on soil type was available.

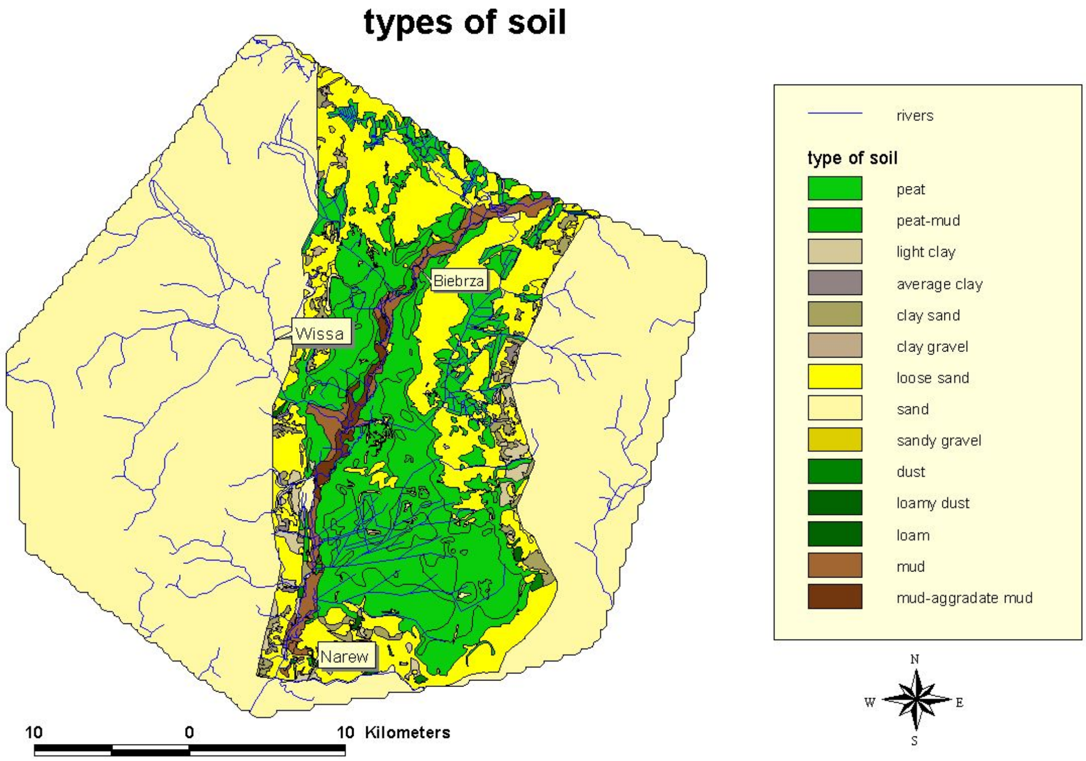


Figure 3.5 Original types of soil

For the purpose of the input data schematisation, the types of soils were changed according to AlterrAqua program demands. The identified soils (recognised by the AlterrAqua) and percentages of the covered area are presented in table 3.2 and further on in figure 3.6.

Table 3.2 Types of recognised soils based on AlterrAqua requirements

Type of soil	% of the area
Clay on sand	0.5
Eolian cover sand	0.1
Humified top soil on deep peat	20.0
Humified top soil on peat on sand	0.3
Light clay with homogenous profile	0.8
Loam	0.2
Sand	75.8
Sand cover on peat on sand	2.5
Total area (133 764 ha)	100

As can be seen in table 3.2, from an original detailed categorisation of 14 soil types, for the purpose of recognition of input data by the AlterrAqua model, eight types of soil were defined. Figure 3.6 shows the model area based on the new classification of soil types, and by comparing it with figure 3.5 the differences can be noticed.

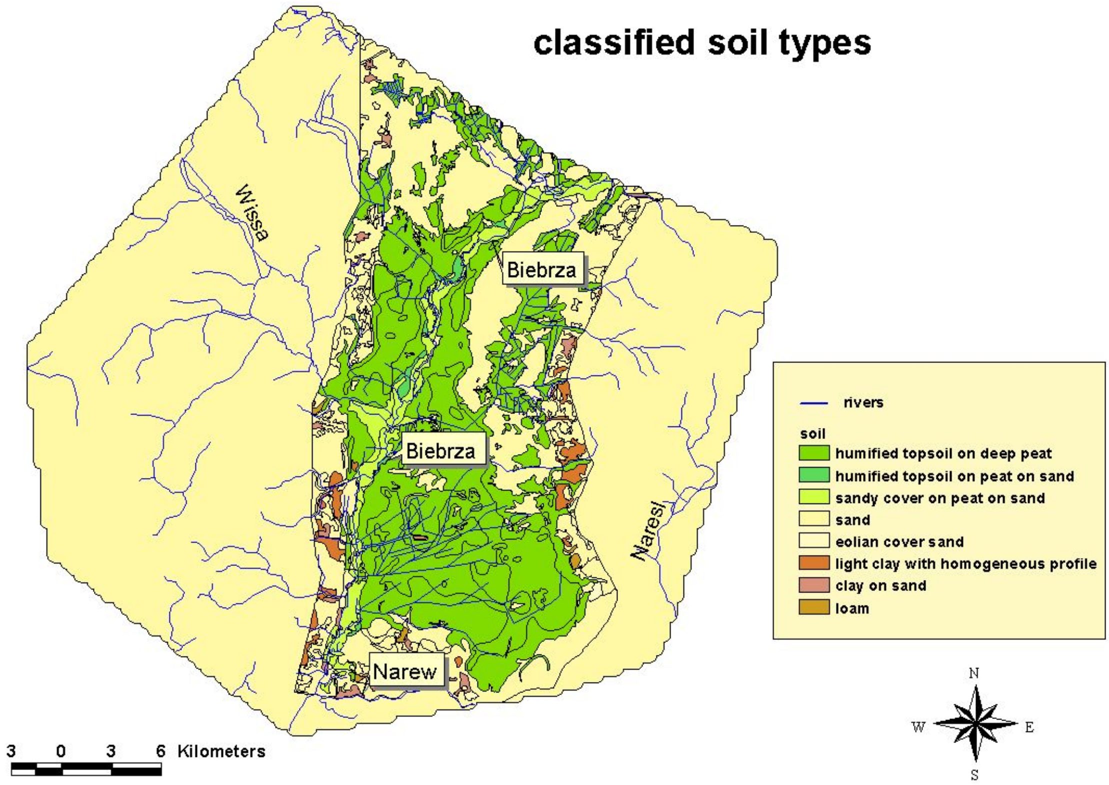


Figure 3.6 Classified types of soils based on AlterrAqua requirements

3.3.2.3 Land use

Almost the entire area is covered by organic soils with different thickness and it is used mostly as grassland for meadows or pastures and as woodland in some places. Within the modelled area, many sandy regions are recognized and cover about 60% of the total area. They are mostly used for agriculture purposes (table 3.3 and figure 3.7).

The Biebrza valley is covered in a large extend by organic soils and due to these natural conditions the area is overgrown by fen vegetation, but also used as a meadows, pastures and forests. Because of different soil types, several types of land use were documented by the use of topographic maps and land use maps of BNP. On the basis these sources the AlterrAqua input data of land use was defined, taking into account the schematisation that was necessary for input data demands. It was assumed that the area of the valley is covered by peatland with meadows, pine forests and forests in wetlands (figure 3.7).

The upland terrains were investigated with minor importance. Based on interviews together with literature research it was assumed that the mineral formations on uplands are managed by agricultural use.

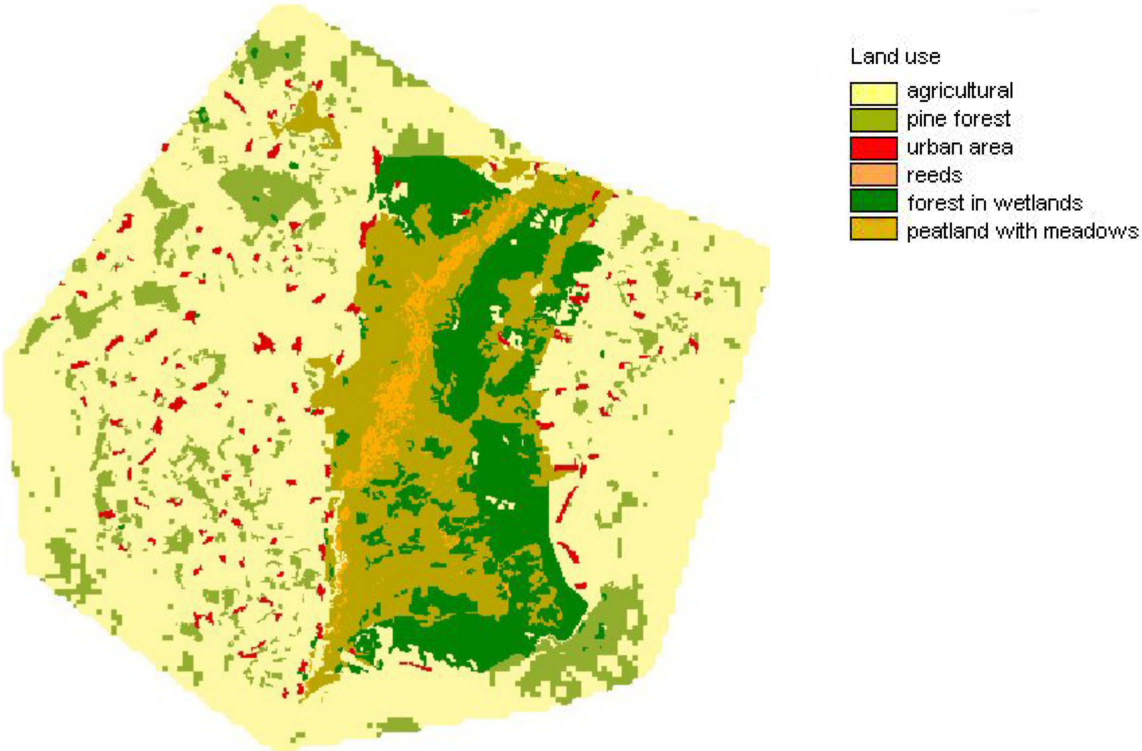


Figure 3.7 Type of land use

As shown in table 3.3 almost 60% of the research area is used for agricultural purposes and 22% is covered by forest. Agricultural activity concentrates especially outside the borders of Biebrza National Park (figure 3.7).

Table 3.3 Classification of different land use

Type of land use	% of the area
Agricultural	59.9
Pine forest	10.1
Urban area (cities)	1.9
Reeds	1.3
Forest in wetland	12.2
Peatland with meadows	14.4

3.3.3 Calculation of the hydrology

3.3.3.1 Boundary conditions

Boundary conditions were defined for the calculation period (1990-1995). Both groundwater boundary conditions and surface water boundary were estimated.
Groundwater conditions of the modelled area (groundwater discharge) are specified in figure 3.8. The discharges from the gauge stations Osowiec for Biebrza river (East upland) and Wissa (West upland) were used as input data for the calculations.

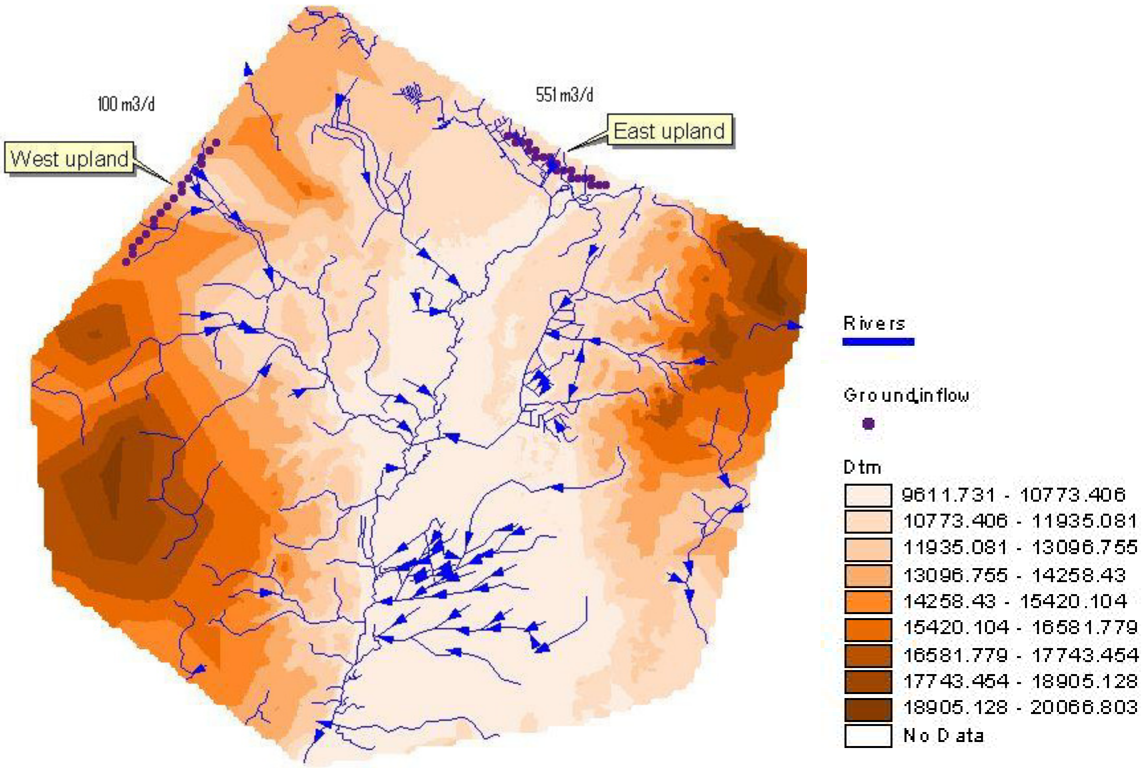


Figure 3.8 Groundwater boundary conditions

Characteristics of groundwater inflows from the north-western upland and from the valley (north-eastern side of the studied area) to the boundary nodal points were essential to estimate, and this data (rate of inflow in $m^3 \cdot d^{-1}$) set the initial inflow boundary conditions. The amount and direction of inflows rates were estimated based on earlier studies conducted on this area together with studies of groundwater izolines and expert judgement. The inflow rates into the west upland is 100 $m^3 \cdot d^{-1}$ and into the north-eastern part 551 $m^3 \cdot d^{-1}$ (figure 3.8).

Boundary conditions for surface waters (rivers) were set variable in time (Dirichlet boundary conditions with given heads). Daily river flows in inflow points situated on rivers (see figure 3.9) are specified as the surface water inflow into the studied area. Figure 3.9 shows the inflow points, which are displayed on:

- The north-western upland, were Wissa river flows into the model
- The north-eastern side of the model, where the measurement stations are situated (Przechody and Osowiec) on the Biebrza river

Taking measurement in point 'W' as a 100% reference point of daily discharges ($m^3 \cdot s^{-1}$), it is estimated that the Wissa inflow point covers 30% of this discharge. Przechody and Osowiec are the inflow points where daily measurements were conducted on gauge stations in Przechody and Osowiec respectively.
For the purpose of calibration and verification of the model, reasonable data sets from measurement points (gauge stations) were needed. Gauge station Burzyn and 'W' (on the Wissa river) were used to compare measured with calculated data.

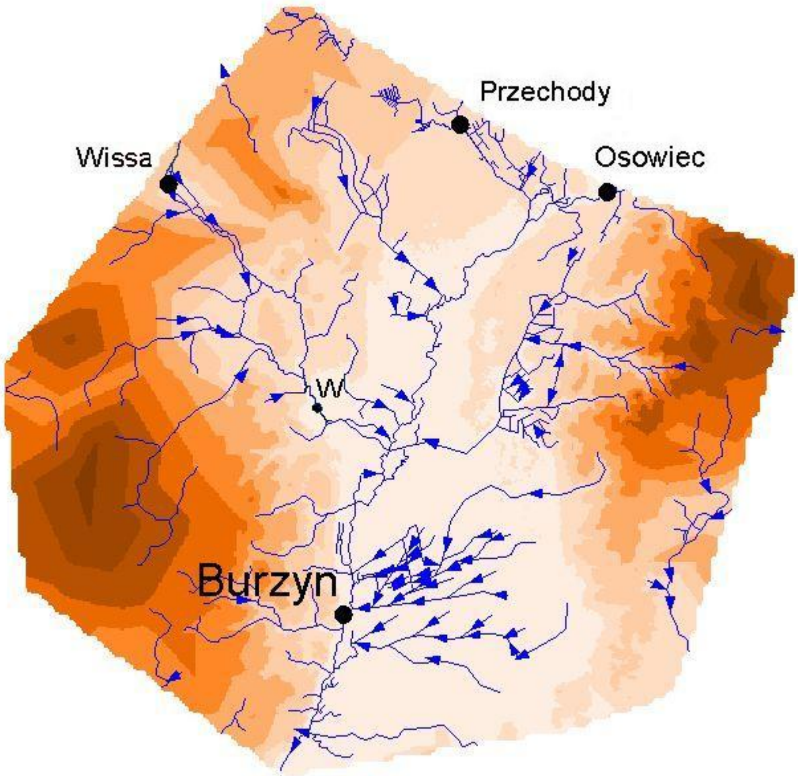


Figure 3.9 Inflow points of surface water into the boundary nodal points

3.3.3.2 Surface water network

For the purpose of modelling the surface water network, schematisation was needed and assumed as follows:
- Main watercourses (Biebrza river, Narew river)
- Smaller watercourses (the tributaries of main rivers, for example Wissa)
- Drainage-irrigation system of ditches (with the drainage purposes)
- After defining these types of surface water channels, mentioned above, the geometrical dimensions had to be specified. Geometry of the drainage system was defined according to standard AlterrAqua data requirements, which

describe in a simplified matter the geometry of the system as well as the density of the drainage network.

- Considering main and smaller water systems the geometry dimensions had to be specified for each part of the watercourse. The specification was based on:
- Field measurements
- Topographical maps
- Existing transsections
- Experts knowledge
- The geometry of channels (water courses) had to provide following information:
- Depth
- Width of river bed
- Width of water courses at ground level
- Side slope

All this information was necessary for assigning adequate hydraulic conditions of channels for the purpose of defining and describing natural relationships between surface and groundwater.

Earlier in this paragraph the measurements stations were mentioned. Hydrological data was necessary to obtain for the period on which the model simulation was conducted. This way it was possible to compare for example modelled discharges or surface water levels in Biebrza river with the real measurements. Keeping in mind as well the necessity for further calibration of the model, measurement points were defined and available data were obtained. As mentioned before discharges data with daily flows at chosen gauge stations (Osowiec, Przychody and Burzyn on Biebrza river and 'W' point on Wissa river) were needed.
In table 3.4 the characteristics of the channel dimensions of the water courses have been summarised.

Table 3.4 Channel dimensions of characteristic watercourses

		Dimensions of watercourse			
Watercourse	**Type of channel**	*Depth (m)*	*Width of river bed (m) /in ranges/*	*Width of water courses at ground level (m) /in ranges/*	*Side slope (1: n)*
Biebrza	Main river	1.3-2.1	17-31.8	19.1-35.1	1:1
Wissa	BRtr[1]	1.5-5.5	7-10	11.6-17.1	1:1
Kosodka	BRtr[1]	1-3.55	3.512	8.12-14	1:1
Klimaszewica	BRtr[1]	1.61-6	4-6	16-8.6	1:1
Golda	BRtr[1]	2.2-6.35	1.5-4	6.5-12	1:1
Rudzki Canal	BRtr[1]	2.9	13.3	26	1:1
Naresl	Nrc[2]	2.5	3	11	1:1
Narew	Main river	3	31	33	1:2
Drainage ditches	-	1	1	3	-

1 BRtr: Biebrza river tributaries
2 Nrc: Narew river catchment

Watersheds were created by AlterrAqua using information of DTM and the surface water system. A map of watersheds is displayed in Appendix I.

3.3.3.3 Groundwater level

Groundwater levels of the modelling area were the essential for conducting the research. It was possible to acquire several measurement data on the groundwater level, although not always complete within a certain time period. Measurements stations (piezometers) are situated nearby the Biebrza river, as can be seen in figure 3.10. In Gugny measurement station 9 piezometers are situated, but only data from piezometers number 5, 6, 7, 8, 9 were available and relevant for the study. More information concerning piezometers is included in paragraph 3.5, where the calibration of the model is evaluated on.

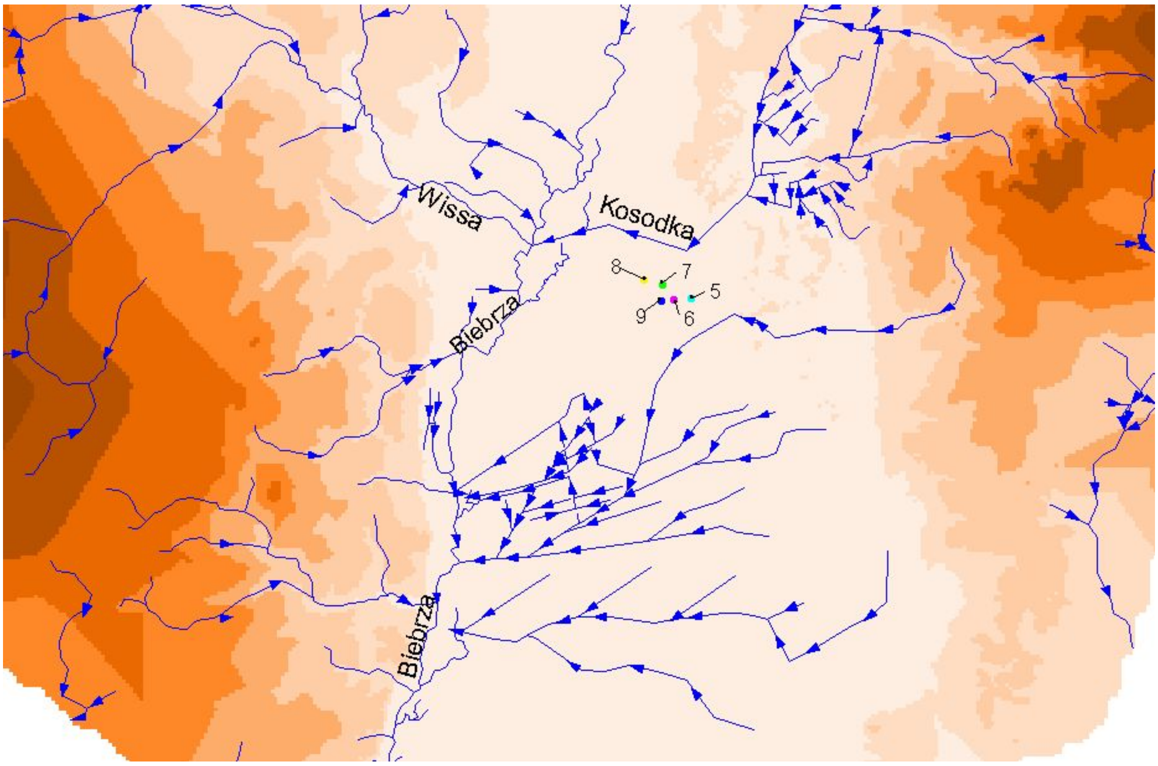


Figure 3.10 Location of piezometers

3.4 Model calibration

The model was calibrated for the weather conditions of 1992-1993, using the measured discharge at Burzyn gauge station, together with surface water levels and groundwater levels measured at different locations. Because of the long winter conditions it was necessary to include in the Simgro model the process of snow accumulation and snow melting. For the discharges this improved the model quite a bit.

Scenario 0 is considered to describe the present situation, such as hydrographic network and land use in the valley. This scenario is used as the reference to compare it with the management scenarios. The scenario simulates conditions for the period of 1990-1995.

3.4.1 Scenario 0

To improve Scenario 0, a limited number of changes to the surface water input data was carried out, related to the stage-discharge relation of the Biebrza River in the model. Two variants were considered:

- Variant 1: The dimension of the main channel of Biebrza river was assumed in such a way were the width of water courses at ground level was as displayed in table 3.4 in the previous paragraph (surface water courses).
- Variant 2: The Biebrza River was considered wider, being 75 m at ground level and side slopes of 1:2. The Biebrza River in Variant 2 is schematised in such a way that more emphasis is given to natural conditions of the channel dimension at the ground level. The results for both variants are discussed below.

3.4.2 Model results for variants 1 and 2

3.4.2.1 Variant 1

In Variant 1 the ratio of the discharges of the main Biebrza river channel was changed (the relation Q/H has been changed in certain parts of the main channel of Biebrza river).
Due to the large number of gathered outputs, the visualisation of results from the period of the simulation (1992-1993) was done for one particular day. The results for surface and groundwater levels are presented in figure 3.11 and 3.12, and consider the modelled situation for the 91ts day of the year 1993.

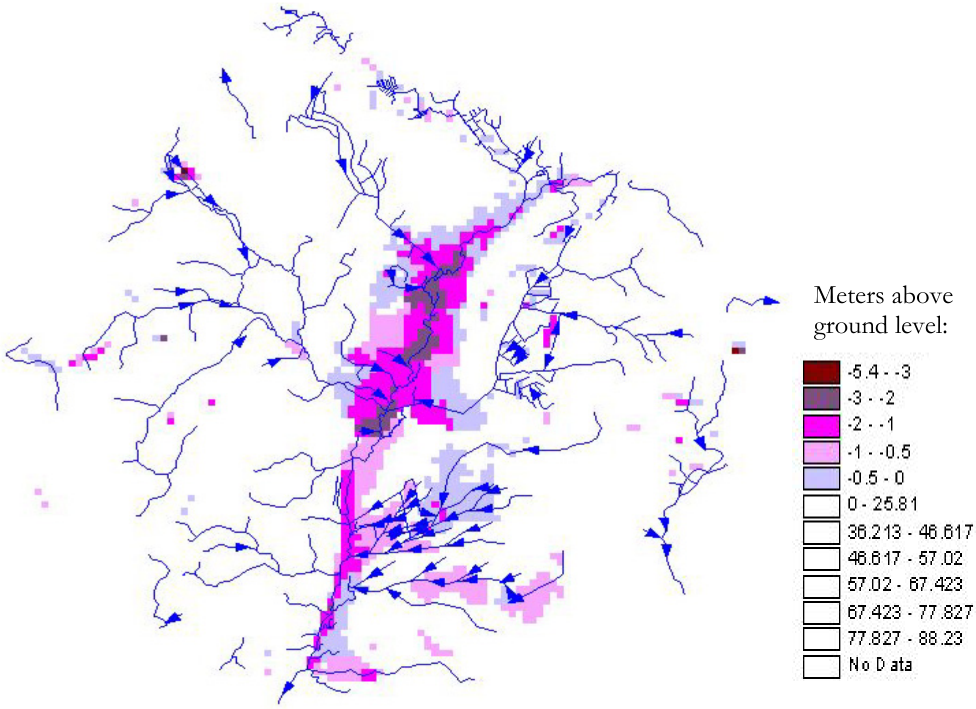


Figure 3.11 Variant 1: Surface water level, regional inundations (1st of April 1993)

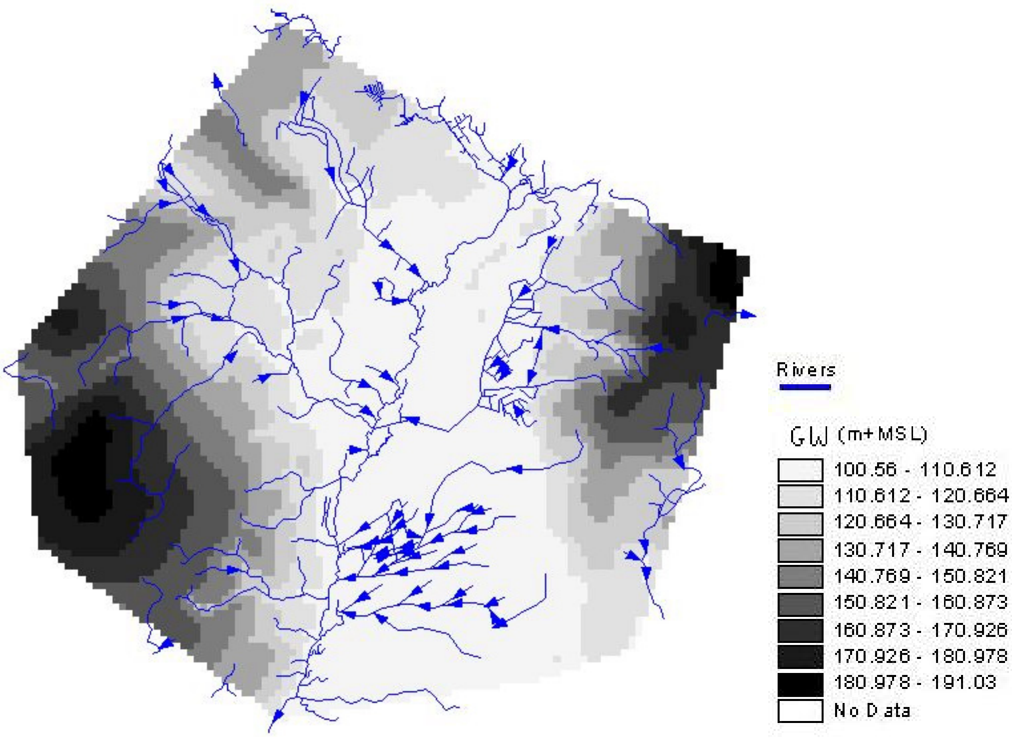


Figure 3.12 Variant 1: Groundwater level (1st of April 1993)

3.4.2.2 Variant 2

Variant 2 simulates the changes in dimensions of the Biebrza riverbed at the terrain level. Since the model considers the river courses as a channel with certain geometry (slope side, river button wide, etc.), the dimension of the channel at the ground level was estimated with very high embankments, which might cause errors. To correct possible errors, in Variant 2 it was assumed that the dimension of the channel at the ground level would be enlarged up till 75 meters.
The simulation was made for the same period as Variant 1. The results were displayed for the same day of the simulation period (1st of April 1993), to make a reliable comparison possible. The results for surface and groundwater levels are presented in figure 3.13 and 3.14.

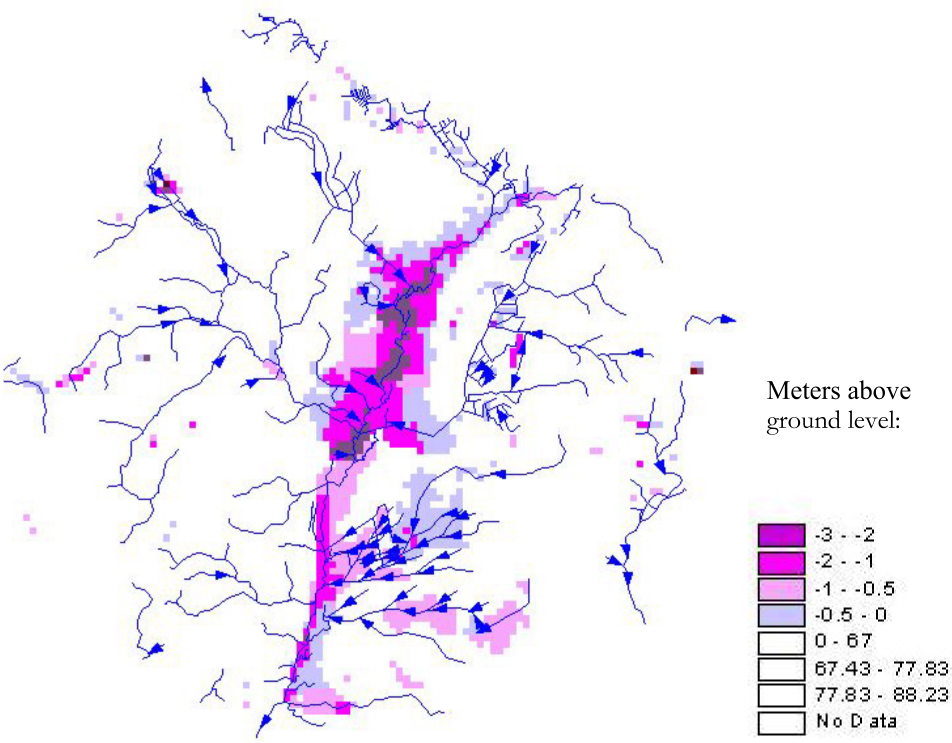


Figure 3.13 Variant 2: Surface water level, regional inundations (1st of April 1993)

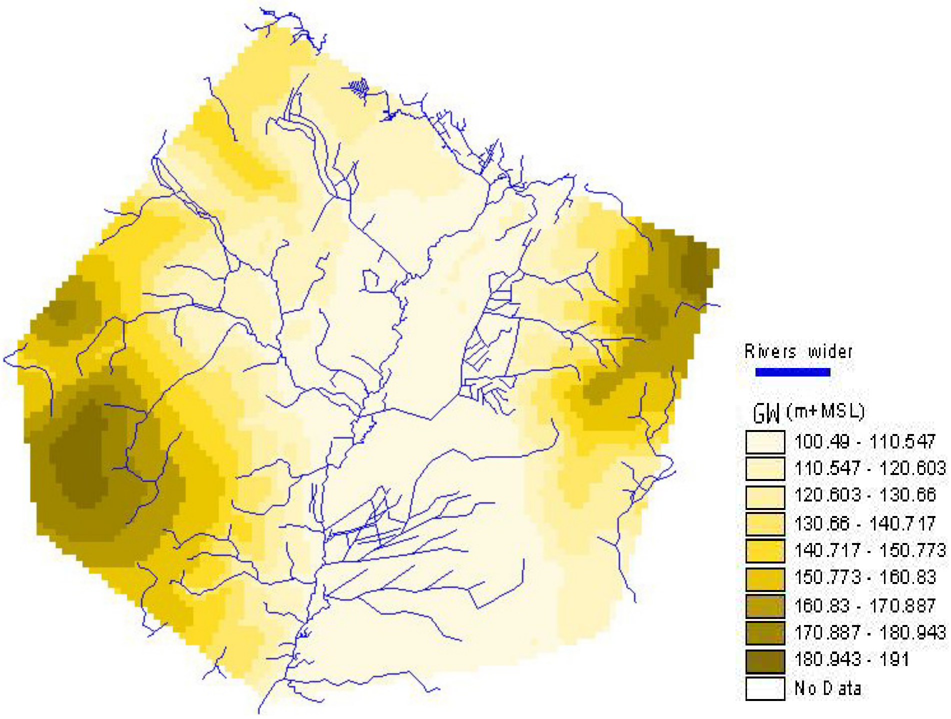


Figure 3.14 Variant 2: Groundwater level (1st of April 1993)

3.4.2.3 Further improvements to Scenario 0

A more accurate prediction of discharges (Q/H relation) of main Biebrza river channel in the model, as well as the correction of the main river channel dimensions (width on ground level) contributed to a further and more realistic adjustment of Scenario 0.

Based on the outcome of the analysis of the two different variants mentioned earlier, Scenario 0 was established to be further calibrated upon. After correction of the afore discussed discharges and dimension of the riverbed, Scenario 0 was simulated. Surface and groundwater levels are displayed in figure 3.15 and 3.16.

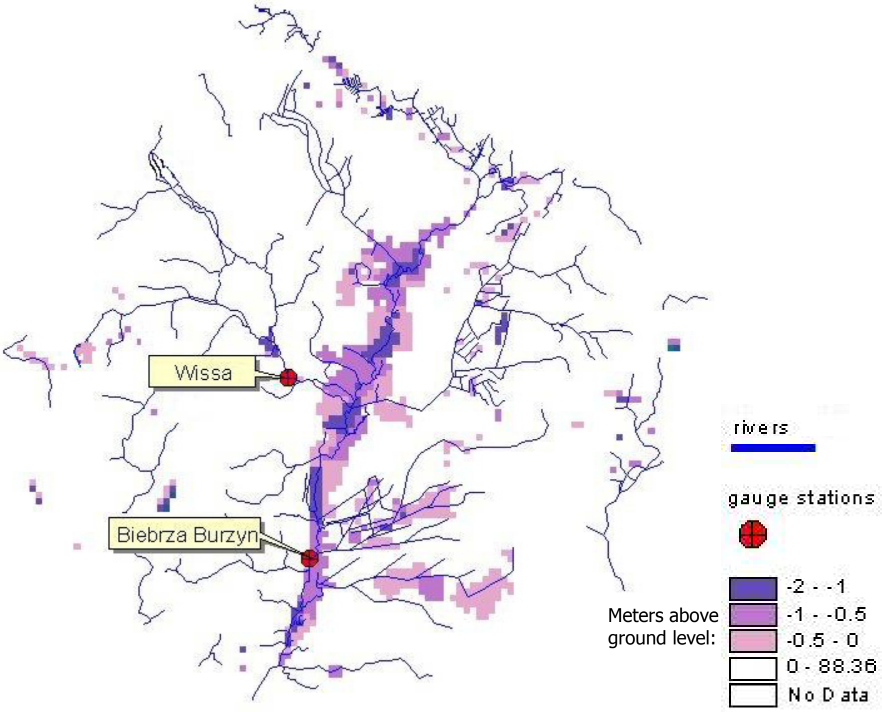


Figure 3.15 Scenario 0: Surface water level, regional inundations (1st of April 1993)

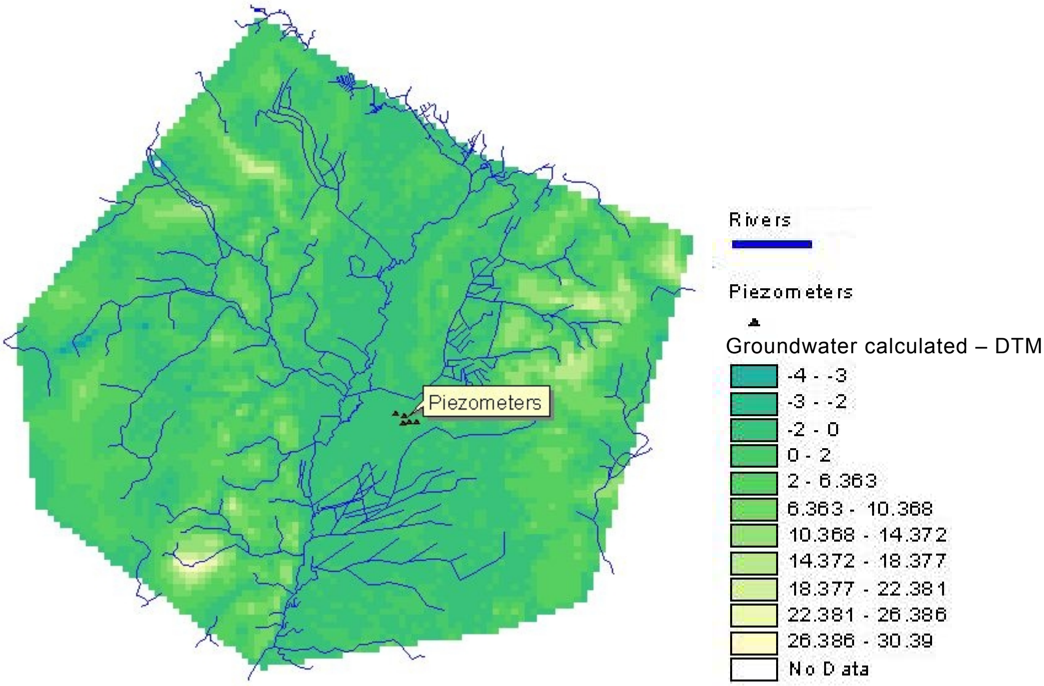


Figure 3.16 Scenario 0: Groundwater level (1st of April 1993)

3.4.3 Final improvements to Scenario 0

AlterrAqua interface was build for the purpose of modelling surface and groundwater levels, but default values considered Dutch conditions. Due to major differences in atmospheric conditions between the Dutch and Polish climate, it was crucial to improve the model even more. In Poland the vegetation period is shorter and the winter season is longer. The geographical region where Biebrza catchment is situated is known as one of the coldest regions in the country. To improve input data of the surface runoff, the snow melting was added to the model as an additional component.

To calibrate the model more precisely, further verifications were made based on:

- Groundwater level (measured in several piezometers);
- Observation of surface water discharges (measured discharges in Burzyn and Wissa gauge stations).

3.4.3.1 Groundwater level

The differences between observed and calculated groundwater levels were analysed for the 5 piezometers displayed in figure 3.10. The measurements observed in piezometers were compared with the nearest nodal points of the model to be able to compare the measurements (in piezometer) and the groundwater level calculated by the SIMGRO model. The comparison can be analysed in figure 3.17, which represents:

- Daily measured groundwater level for the period of 4-01-1994 until 12-12-1995
- Daily calculated groundwater level for the same period of time

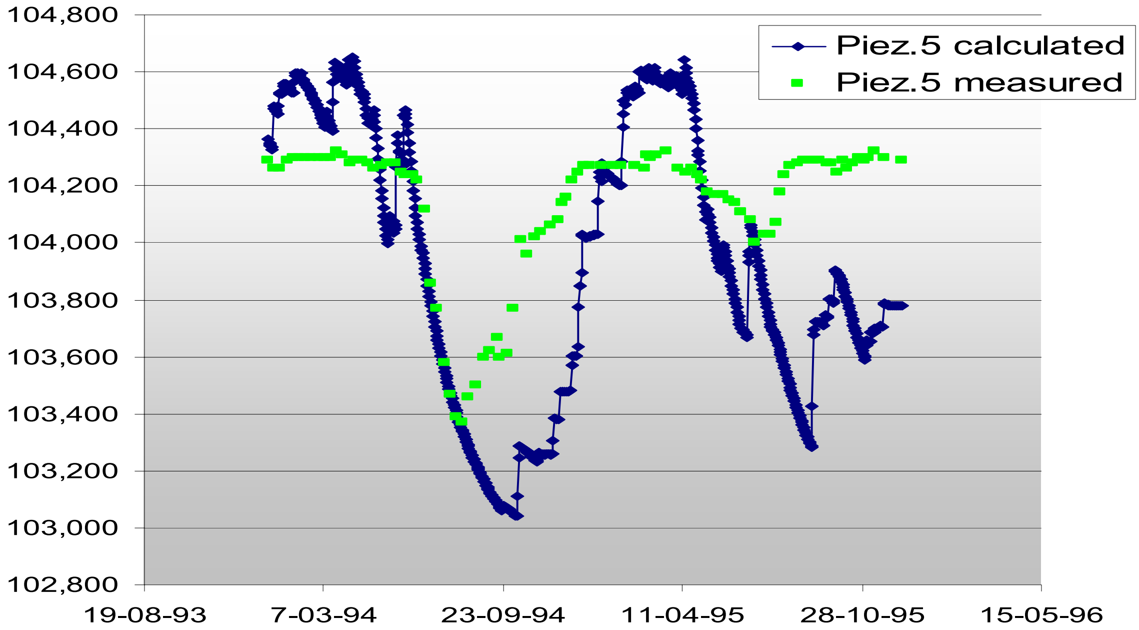


Figure 3.17 Measured (green) and calculated (blue) groundwater level

The comparison was made in chosen nodal point 4743 of the model, which is the nearest to the piezometer 5. For each of chosen nodal points the measured groundwater level was compared to calculated level, as it was done for piezometer 5. Table 3.5 indicates the piezometers with their respectively nearest nodal points and the ground level.

Table 3.5 Number of piezometers with the nearest nodal point

Nodal point nr.	Ground level	Piezometer nr. (measurement station)
4743	104.77	5
4742	104.37	6
4640	103.90	7
4639	103.72	8
4741	104.02	9

The correlation between calculated groundwater level in the nodal points 4743 and measured in the piezometer 5 is satisfactory. Due to the schematisation of physical processes precise correlation will never be obtained. However, the correlation of the calculation outputs seems to be realistic and this is the confirmation that the model works properly.

3.4.3.2 Discharges

The comparison of surface water was made for measured and calculated discharges. The gauge stations, as mentioned earlier, are located along the Biebrza River (Burzyn gauge) and along the Wissa River (figure 3.15). The measured discharges were compared with the calculated discharges. Figure 3.18 and 3.19 shows the daily discharges observed and the measured discharges.
Since surface water was modelled as a network of segments, the comparison of discharges were made for specific segments, where the measurement stations (Burzyn, Wissa) are situated in reality. For Wissa segment 383 was assigned, and for Biebrza (Burzyn gauge station) segment 514.

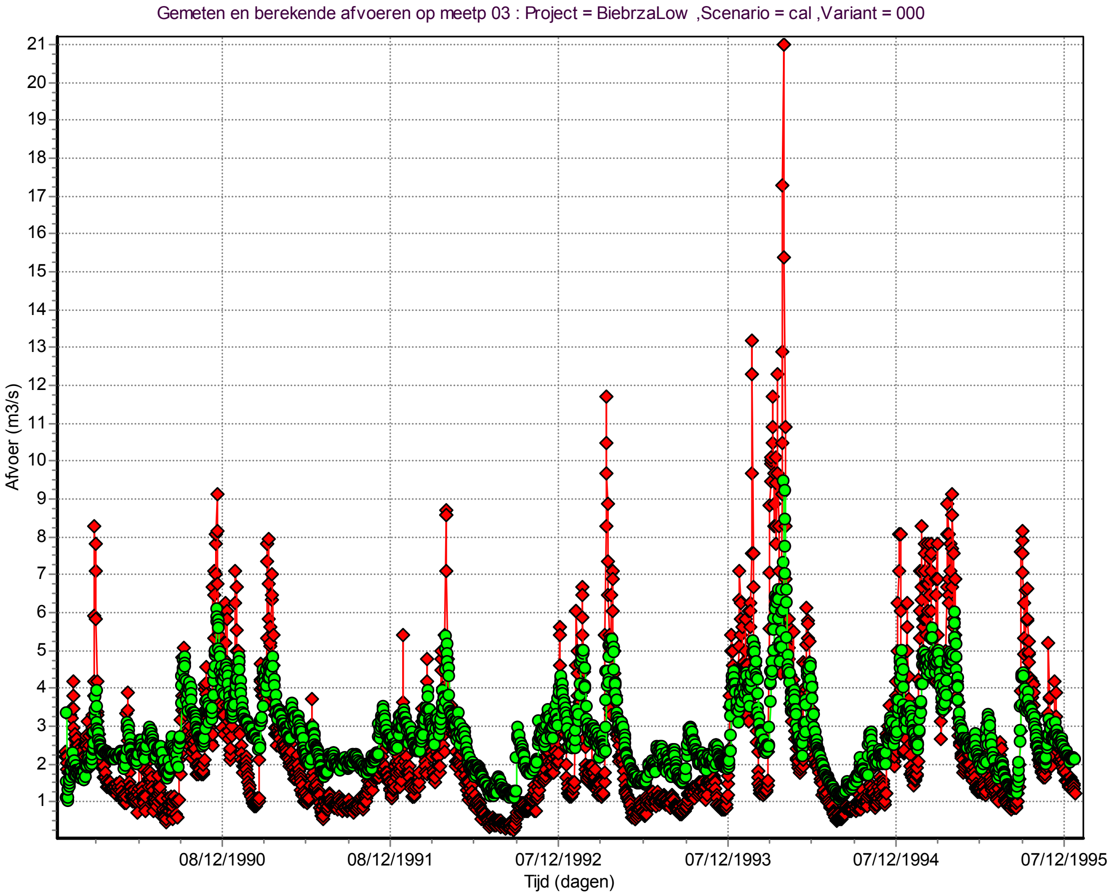


Figure 3.18 Measured (red) and calculated (green) discharges at the Wissa gauge

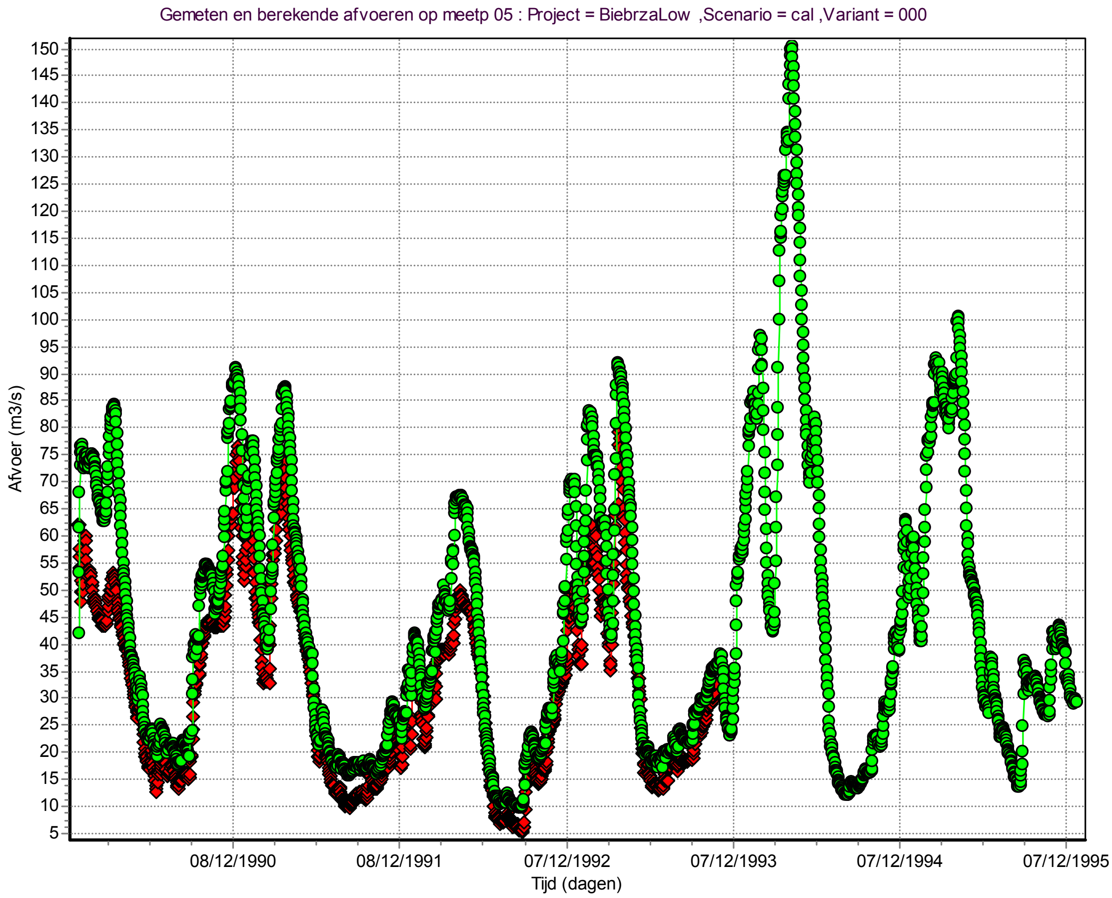


Figure 3.19 Measured (red) and calculated (green) discharges at the Burzyn gauge

3.4.4 Conclusions

To obtain an accurate Scenario 0, the model has been undergoing thorough calibration. To verify the model the calculated and measured levels of groundwater and surface water were compared. Certain parameters had to be corrected or adjusted to represent calculated water levels similar to the measured levels. A major improvement was obtained by experimental modelling with the component of snow melting, which resulted in a more accurate surface run off parameter.
In the end, the calculated and measured discharges of Scenario 0 compare quite well, with only slight differences. Therefore this scenario is suitable to be used as a reference to which other management scenarios will be compared in the following chapter.

4 Scenarios

In the previous chapter Scenario 0 was considered, which represent the present hydrological situation, and serves as a starting point to explore future management options and possible plans. In this chapter two different scenarios will be designed and modelled, and their effect on groundwater levels will be displayed. Based on the outcome of these scenarios, subsequently policy options for water management in the Lower Biebrza Basin will be proposed.

4.1 Different scenarios as a management tool

The modelling of natural conditions is always very difficult, especially when it comes to the delicate balance of physical variables. It is important to collect all needed data, maps or field observations. Sometimes a lack of data forces us to make certain assumptions, to 'predict' the conditions.
After verification and calibration of the model, Scenario 0 has been displayed as the reference scenario to which management scenarios will be compared. In this way the Lower Biebrza SIMGRO model can be used as a proper water management tool, by predicting the impact of various activities on water resources of the peatland area.
Two different scenarios are modelled to calculate the impact of natural and anthropogenic factors on water conditions. Because it is possible to simulate different situations, this forecasting method may be taken into serious consideration by stakeholders and environmental scientists, who are involved in the decision-making of the Biebrza Basin management policy.
Depending on what changes may occur due to certain pressures on environment, the scenarios can simulate a '*what if…*' situation. Two main scenarios were taken into consideration. The characteristics are described below.

Scenario 1
The Biebrza valley acts as a refuge area for many rare fauna species. It is the most important breeding place in Central and Western Europe for several threatened birds. It is also an important fuelling station for migrating spices such as geese (Sienko, 2003). For those species the vegetation succession of the abandoned peatlands is a serious threat. The peatland area needs to be under constant maintenance, due to rapid succession of vegetation (Wassen et al. 1990).
Without certain managing of the area, for example harvesting of grass and reeds, after some time the bushes and lower trees replace the grass communities. On a terrain of natural wetlands where no action management is performed, natural succession takes place with forestation as the last phase (Werpachowski, 2003).
This process could have remarkable effects on the groundwater levels, which would subsequently give direct negative impacts to the sources of rich flora and fauna of the wetland region.
Taking this problem under close consideration, Scenario 1 was created. Scenario 1 considers an option, where changes would take place in land use, due to natural

succession. The basic presumption was that the valley would be overgrown by forest as the last stage of natural succession. This is possible in the case of 'no action' management of the area. In Scenario 1 this presumption was schematised by replacing peatland by forest land use in the valley areas (figure 3.7).

Scenario 2

Scenario 2 considers a man-made approach, which is the opposite of scenario 1 where the main threat was natural succession. Changes in distribution of surface waters and thus also the groundwater table depth in the modelled area may affect the water balance of the valley. In this scenario, the main concern is focused on local changes in the drainage-irrigation system.

It was assumed that the drainage system placed on the terrain of the right Biebrza riverbank would be disabled for the purpose of local improvement of water conditions.

4.2 Calculation of the management scenarios

The major sources of water come from the surrounding uplands. They feed both the main rivers the Biebrza valley and its flood plains. The size and the distribution of the valley water system depends on the hydraulic conductivity of the peat and the underlying sandy soil, but also on changing precipitation and evapotranspiration patterns throughout the year.

Different visualisations of changes in groundwater levels can be presented. For Scenarios 1 and 2 the Average Low Groundwater in summer (GLG[3]) level has been visualised.

4.2.1 Scenario 1

The simulation has been conducted for the period of 1-1-1990 until 31-12-1995. To be able to compare different scenarios, the time variable had to be the same for Scenario 2. The results after calculation of the scenario, the results of groundwater levels were calculated.

Negative impact on groundwater balance caused by forestation has been confirmed by the results. Due to the enlargement of evapotranspiration by the forests area, the level of groundwater radically lowered in comparison to Scenario 0.

Changes in groundwater level directly disturb the ecological balance of wetlands. The appearance of this situation in reality could cause severe changes on the entire area in complex dimensions (flora, fauna, and regional water balance changes). The most important possible effects are listed below:

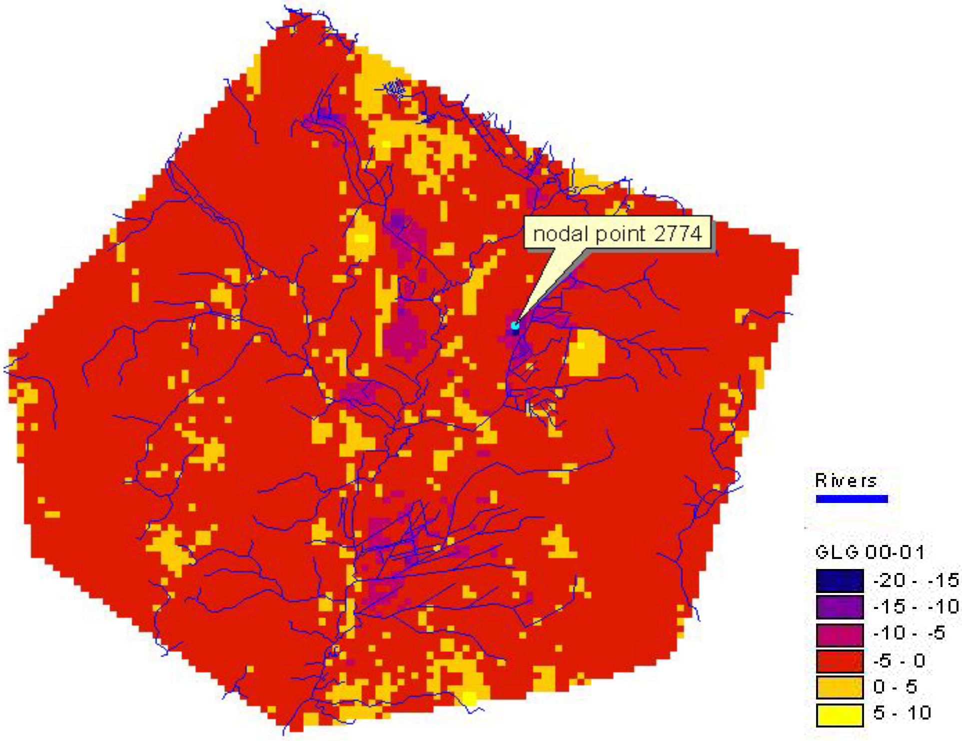
- The impact on flora could result in changing plants communities, and several species which are placed on the IUCN[4] Red List of endangered species could be extinguished

[3] Gemiddeld Laag Grondwater = Average Low Groundwater level in summer

[4] International Union for Conservation of Nature and Natural Resources

- The impact on fauna could result in the disappearance of a large number of breeding birds, which can not find proper places for nesting and enough food for themselves and their offspring. Storks, for example, are nesting in the area in large numbers.
- Peatlands sources could react by faster mineralization, drying out, and eventually by its partial irreversible destruction, all due to the lowering of the groundwater level

In figure 4.1 the average low groundwater level in summer (GLG) is presented. The most significant changes in groundwater level between Scenario 0 and 1 appear in central valley areas, where the land use type has been changed.



Legend: difference in cm

Figure 4.1 Change in lowest groundwater level in summer: difference between Scenario 0 and 1 (negative values means lower groundwater levels)

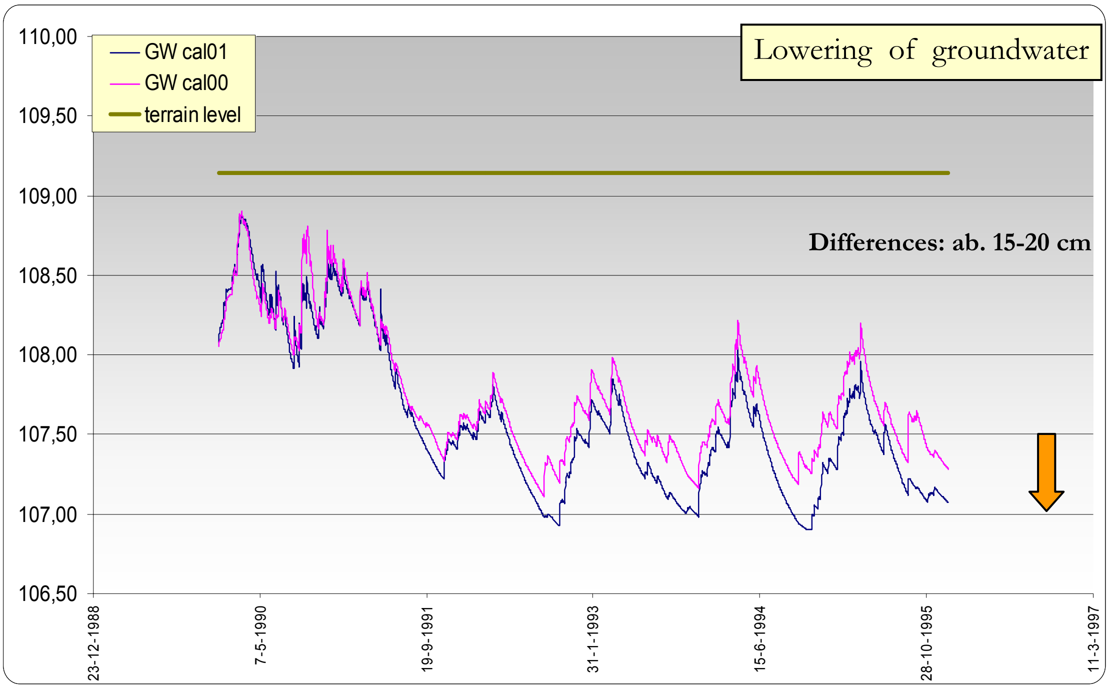


Figure 4.2 Groundwater level in nodal point 2774 for Scenario 0 and 1

Additionally in figure 4.2, the development of the groundwater level between 1-1-1990 and 31-12-1995 for both Scenario 0 and 1 is presented for nodal point 2774. This nodal point is situated in an area where significant changes were estimated; its' location is displayed in figure 4.1.

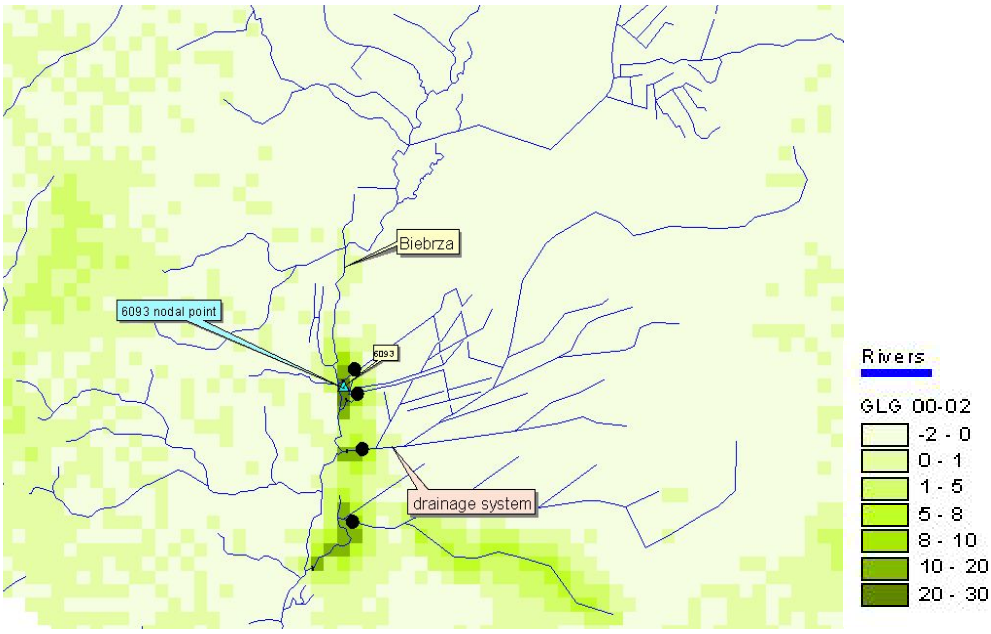
The output of the calculation results in a lowering of the groundwater level due to changes in land use. From existing wetlands and meadows, in Scenario 1 the middle part of the valley was assumed to be overgrown by forest. It caused higher rates of evapotranspiration that eventually made an impact on the groundwater level.
To preserve the proper condition of wetlands in the Lower Biebrza Basin area it is essential to understand and accept that proper maintenance of the pastures and meadows is essential and necessary. Nowadays many management concepts appear to be as natural as possible, which results in non-action activities plans. In fact, not everybody realises that with such a non-action 'pro-nature' policy, irreversible changes of the water regime may cause remarkable negative impact to the peatlands' natural values.

On the basis of modern environmental management practices, it is known that active management (for example by mowing) is crucial for open peatland areas in order to preserve them. A significant problem appears when the ownership of open peatlands is considered, they are in a large extend privately owned. Within the ongoing battle between land owners who are focused on agriculture on the one hand, and nature lovers and scientists who want to preserve the satisfactory conditions of water regimes on the other hand, it is a challenge to find a proper balance between agricultural and nature interests.

4.2.2 Scenario 2

The simulation for Scenario 2 is conducted for the same time period as Scenario 1 (1-01-1990 till 31-12-1995).
In this scenario, the main concern is focused on local changes in the drainage-irrigation system. It was assumed that the drainage system placed on the terrain of the right Biebrza riverbank would be disabled. Four channels of drainage system were blocked nearby the main Biebrza riverbed, as shown in figure 4.3.

In figure 4.3 the average low groundwater level in summer (GLG) is presented. After blocking of small drainages (figure 4.3) the regional inundations appeared, which resulted in an increase of the level of groundwater. The most significant changes in groundwater level between Scenario 0 and 2 appear downstream of the disabled drainage system in the Biebrza river. The differences vary from few up till 30 centimetres, depending on the nodal point that is evaluated.
In figure 4.4, the development of the groundwater level between 1-1-1990 and 31-12-1995 for both Scenario 0 and 2 is presented for nodal point 6093. This nodal point is situated in an area where the most significant changes were estimated; its location is displayed in figure 4.3.



Legend: difference in cm

Figure 4.3 Change in lowest groundwater level in summer: difference between Scenario 0 and 2 (positive values means higher groundwater levels)

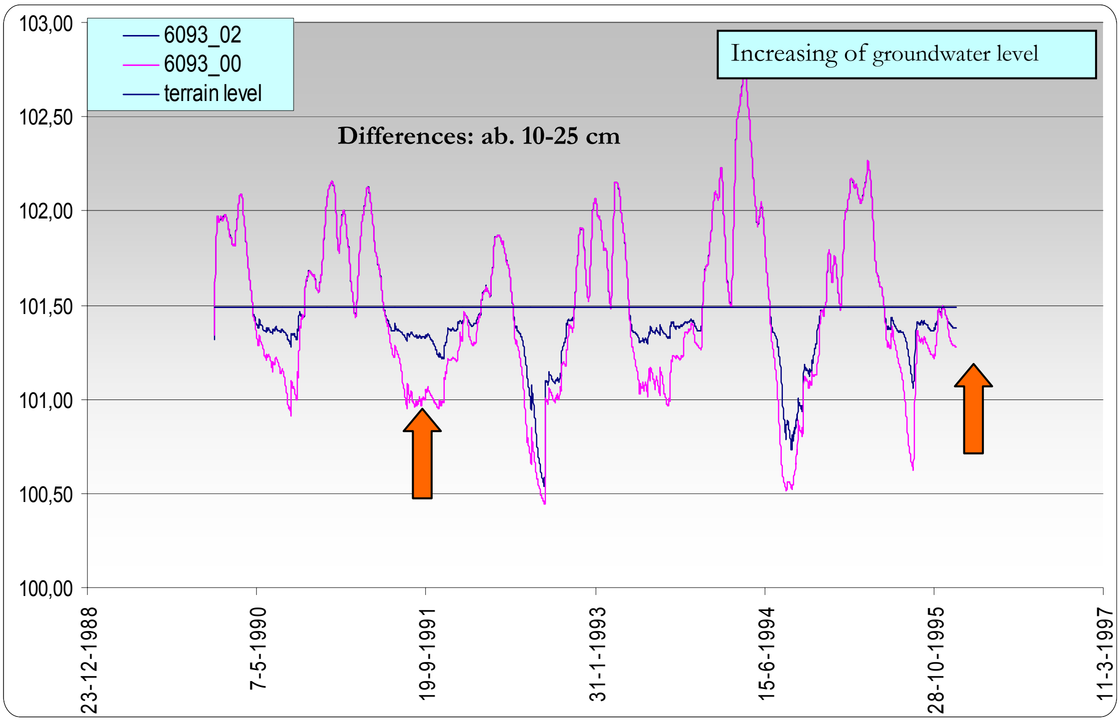


Figure 4.4 Groundwater level in nodal point 6093 for scenario 0 and 2

This scenario was designed to check which changes in groundwater level could be expected by blocking the existing drainage system on the right Biebrza riverbank. Four ditches out of the dense drainage network were disabled and subsequently the water level changes on regional scale were calculated.

A next step of the research with regard to the issues tackled by Scenario 2 could be the creation of a scenario where the whole draining ditches network would be disabled and only natural streams would be left.
Such a research might give very interesting results, for instance by reminding us to the hydrological network status from the period before any drainage works were conducted. This concept may show the natural water regime of the valley, untouched by man-made changes.

4.3 Conclusions

One of the greatest threats to the Lower Biebrza Basin area is artificial drainage, which results in the invasion of marshes by shrubs and trees. The loss of moss communities is accelerated by drainage activities of farmers (landowners). A significant part of the terrain within Biebrza National Park is privately owned, approximately 46% of the park area (Wassen et al., 1990). Pro-agricultural management competes with preservation principles. The conditions of the nature area which is situated within the BNP (where nature conservation is promoted by the legal status of the national park) are strongly connected with and influenced by developments in nature outside the borders of BNP but within the Biebrza river basin. Only dialogue between all involved stakeholders, which are for example landowners, scientists, decision-makers and even outsiders such as nature lovers and bird watchers, may bring positive effects towards mutual understanding and pro-nature actions. The dialogue may be supported by specific and detailed research that present relevant expertise. Forecasting methodology may provide simulations in which scenarios with appropriate assumptions are used as a tool to predict reliable possibilities for future development plans. Such a simulation was conducted in this research, where scenarios with specific assumptions predicted possible changes in the hydrology.

The research simulated two possible scenarios. Scenario 1 refers to a situation where no action management is performed, and natural succession takes place with forestation as the last stage. These changes cause irreversible impact to the water regime due to an increase of evapotranspiration. The result is a lowering of the groundwater level in the order of 5 cm to 15 cm. Therefore proper maintenance of the wetlands is needed, such as mowing the grass and grazing cattle, to avoid nature succession and preservation of the valuable conditions.
Scenario 2 describes a situation where the drainage system of the area is partially blocked. The calculated rising of the groundwater table leads to an improvement of the water regime in the order of 5 cm to 25 cm for an area of about few hectare (fig. 4.3). Flora and fauna of the area would benefit from the higher groundwater level.

The study shows that, with regard to the impact on wetland conditions, Scenario 2 leads to positive changes in simulated groundwater levels while Scenario 1 leads to negative changes. In the next chapter attention will be given to the implications of these outcomes for water management policy in the Lower Biebrza Basin area.

5 Discussion

The Biebrza river, together with the wide valley that surrounds it, creates a very complex water system. Through unregulated watercourses with wild meanders, natural conditions are still preserved. High water levels in the area of the Biebrza catchment are the major requirement for the future preservation of its unique wetlands. That is why it is of great importance to understand the forces that influence changes in the water regime.

The water balance in the Biebrza valley area depends on several factors, such as the water flow in the river, which is very much connected to the regional spring floods, the capacity and disposal of atmospheric precipitation and groundwater supply from the nearby uplands, both its quality and quantity
Apart from natural forces, the water regime also depends on several anthropogenic factors, for instance the type of land use in the valley and upland and surface water quality, both of which can improve or worsen the hydrological water balance. To preserve the valuable Biebrza wetlands the moisture of organic soils is demanding high groundwater levels. These may be obtained by seasonal flooding, which feeds the humified soil and prevents its mineralisation. In order to reach this status, proper water management of the area should be conducted.

The best management scenario may be the reconstruction of the hydrological network, which was present before the construction of the drainage system. However this scenario is not realistic due to several limitations as for example lacking financial resources, time constraints, and ongoing discussions about the desired area management plan. But some measures should be promoted such as:

- Priority to preserving the present hydrological network
- Pro-active management of the peat lands in order to avoid natural succession
- Promotion of extensive agriculture focused on bio-products could diminish the nitrogen load into the water system

This research may be seen as a support tool for decision-makers who are responsible for management plans of the Biebrza valley. One of the main results of this research is the model itself, as a tool for finding the best possible management options both from a natural and agricultural point of view. The research clearly showed that an integrated hydrological approach, by using forecasting methodology, gives results that can be used in the evaluation of the effects of water management possibilities. These results can also be the basis of a more comprehensive and profound study that takes into account other factors such as constraints and costs of the different measures and public participation in managing the area.

Mankind is a user of the nature, and stays on the top of the food chain. Even though on the short term destruction of nature might give quick benefits, ultimately from a long-term perspective it is in the self-interest of mankind to promote pro-environmental actions and proper maintenance of nature.

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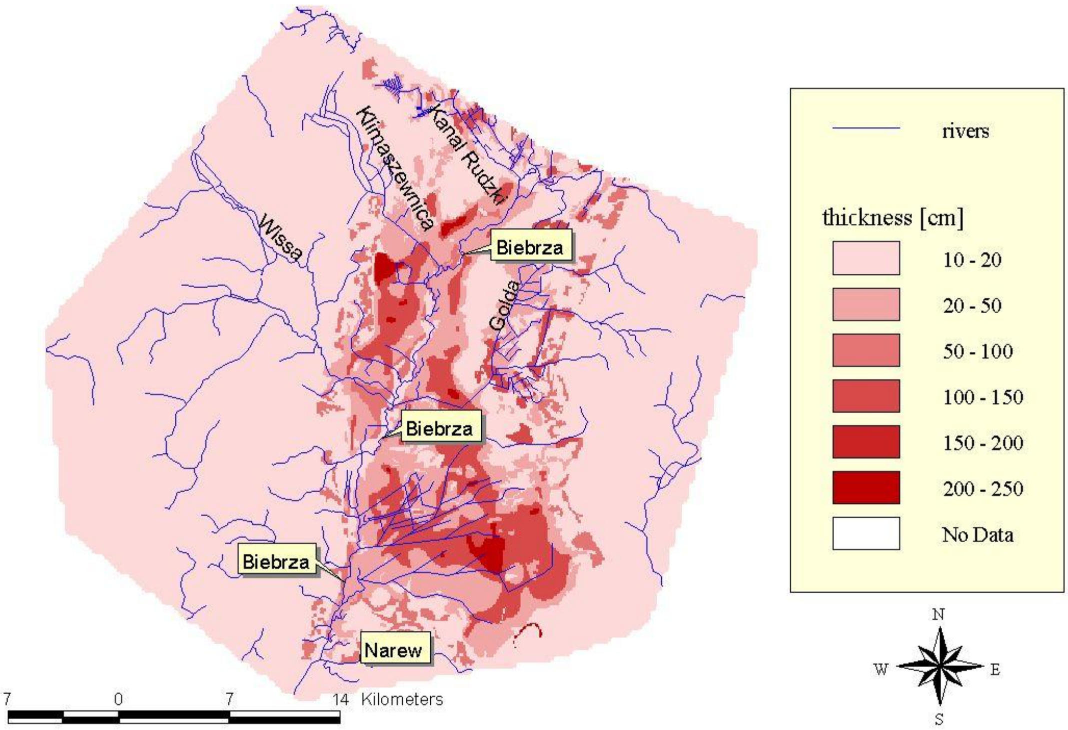
Appendix 1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Kanał Rudzki
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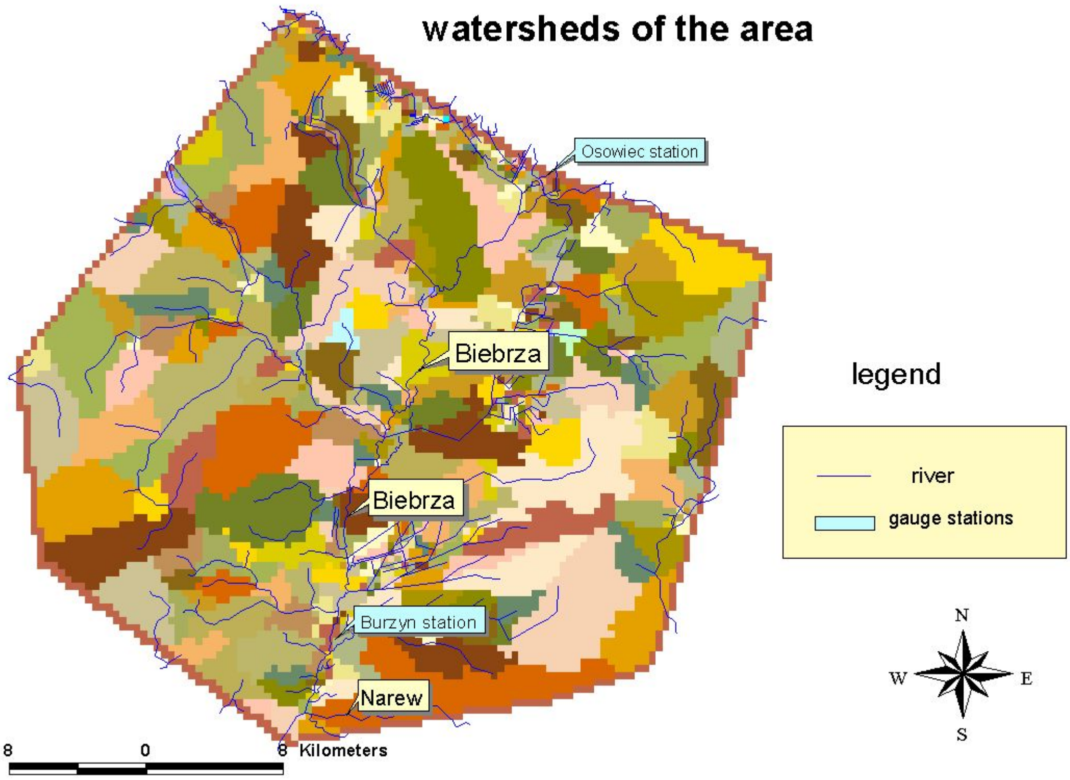
watersheds of the area
Osowiec station
Biebrza
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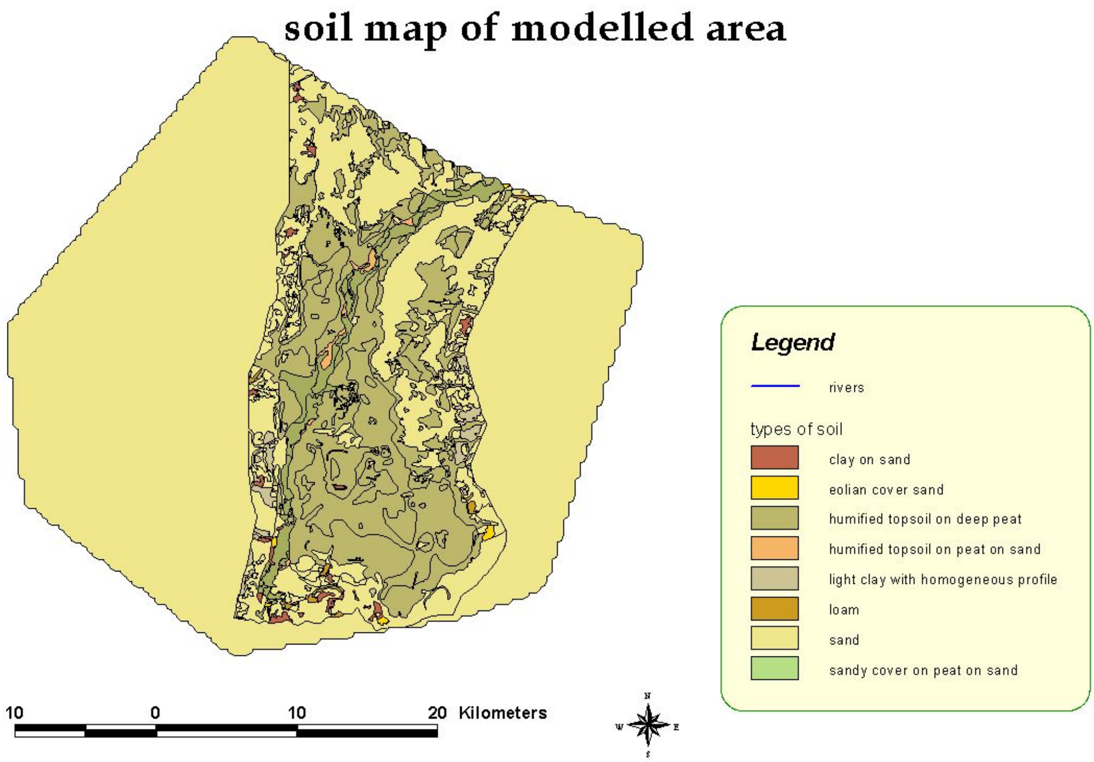
soil map of modelled area
Legend
rivers
types of soil
clay on sand
eolian cover sand
humified topsoil on deep peat
humified topsoil on peat on sand
light clay with homogeneous profile
loam
sand
sandy cover on peat on sand
10
0
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Kilometers