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Modelling of Hydrological Processes in the Narew Catchment

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Preface

Modeling of hydrological conditions in lowland rivers has a long tradition and includes a number of methods which aim at mimic of hydrological processes. Most of the models are developed for the certain purposes like river basin planning, operation of hydraulic structures, environmental impact assessments of particular investments or identification of hydrological properties of different habitats or ecosystems. The purpose of the model shapes its structure, resolution and dynamics.

The aim of this book is a comparison of a number of specific models and modeling methods used in the Narew River basin. There is a strong advantage of comparison of models built for the same area as it illustrates better the advantages and constraints of particular approaches in models used for different purposes. Moreover, the Narew River basin is on one hand a typical river system of Central European Lowlands, but on the other hand it is a basin very rich in valuable habitats and water dependent ecosystems. This means that modeling efforts are also important for recognition and preservation of those values for the future generations.

The Narew River Basin is situated in the north-eastern part of Poland. The Narew River is the fifth largest in the country with regard to river length (484 km) and the size of the basin (ca. 28,000 km^2 before joining the Bug river). The entire basin, except for the most upper part (ca. 1,200 km^2), is located in Poland, but the head catchment is located in Belarus. The basin is developed in the reach of two last glaciations periods: Riss and Wuerm. From north to south the basin includes the following sequence of glacial landscapes types: moraine lake district, outwash plains, ice-marginal river valleys and moraine hills. Sandy soils of various types predominate. During the Holocene the main valleys have been filled up with mesotrophical-eutrophic peat layers which still are partly undrained at present.

Poland is located in a temperate climatic zone in which marine and continental air masses collide. This climate type features characterize also the Narew River Basin. However, due to its location in northeastern Poland the impact of continental air is more visible in the basin compared to the rest of the country. The yearly average temperature is 7.2°C and precipitation equals 617 mm. The river network of the basin is fully developed and rich in tributaries, which mostly originate in the postglacial lakes located in the northern part of the basin. In the lake district region there are more than 500 lakes greater then 1 ha. A few irrigation and navigation channels creates interconnections between lakes and the river network. The flow regime is typical for the lowland rivers in this part of Europe with peak flows after snow melting and regularly appearing low flow periods in the fall of the summer. The yearly average flow recorded in the most downstream gauging station—Zambski Koscielne (before confluence of the Bug and Narew rivers in the artificial lake) equals to 147 $m^3 s^{-1}$, when the average yearly minimum is 55 $m^3 s^{-1}$.

The area of Narew River Basin belongs to poorly populated in the scale of the country. The estimated number of inhabitants of the region is about 1.5 million. On average 55 inhabitants occur for square kilometre of the basin area, while in the rest of the country average population density is more than twice as large, being up to 123 inhabitants per square kilometre. More than half of the population (60%) lives in the cities and towns. The biggest city on the analyzed area is Białystok, the capital city of Podlaskie voivodeship, with 285,000 inhabitants. The other cities are decidedly smaller and none of them exceeds 70,000 inhabitants. All cities have sanitary sewerage systems, transporting effluents to wastewater treatment plants, and storm drainage systems that drain off precipitation water to the nearest receiving water. In most of the cities sewerage network is distributive.

Narew River basin is an agricultural region, with a small degree of industrialization and no heavy industry. Existing production is connected with agriculture and forestry, and is based on local raw materials, which are mainly: milk, meat, cereals, vegetables, fruits and wood. Industries that are developing are mainly agricultural, food and timber processing, and recently tourism. Wastewater from enterprises located in the cities in most cases discharge through the municipal main sewerage system and thence to wastewater treatment plants. Enterprises that are disperse through the basin area have their own effluent treatment. Agricultural land dominates the basin, covering almost 55% of its area. The upland of basin area is mainly used for arable land, the valleys are used as pastures and grasslands. The forestation ratio of the Narew River Basin is slightly over 32%, which somewhat exceeds the entire country average. The largest and compact forest complexes are located in the north, west and east parts of the basin.

The basin is rich in nature areas and resources. The Narew and the Biebrza river valleys are among Europe's last active, regularly flooded riverine valleys. Until now, a considerable part of this area had been utilized for the purposes of extensive (environmentally sound) agricultural practices, thanks to which it still boasts wet meadows of a significant biodiversity value. Additionally in the south-eastern part of the basin, there are number of alder carrs which are groundwater fed. All those habitats are protected in the form of national parks. The vegetation cover of the Narew river valley comprises of several dominating communities such as: reed beds, sedge communities, fens, humid meadows, single mown meadows and herbaceous communities. Twelve water dependent plant communities have been recorded in the valley and listed in the Council Directive 92/43/EEC of

21st May 1992 (Habitat Directive). These are the following: Alkaline fens (54.2), Lowland hay meadows (38.2), Molinia meadows (37.31), Eutrophic tall herbs (37.7), Quaking mires (54.5), Residual alluvial forests (44.3) and Oak-hornbeam forests (41.24).

The Narew and the Biebrza river valleys are also very important areas from wild life existence and protection point of view, especially with regard to bird communities. The valley meets all criteria of Bird Life International. The area is a nesting ground for 90 endangered species out of which 52 are wetland birds. In particular, it is a breeding ground for three species threatened with worldwide extinction and a breeding area for 1% or more of the European population of at least ten species of wetland birds. On the local scale, it is as well very special area being one of the ten most important refuges in Poland for at least 22 bird species. The basin's natural value and importance is emphasised by the existence of three large national parks (ca. 750 km^2) and a vast number of other protected areas (Natura 2,000 sites ca 2,500 km^2, landscape parks ca. 1,300 km^2, strict reserves ca. 170 km^2).

The modeling of hydrological process in the Narew River Basin has been described in eight papers which form a content of this book. Six of them aim at description of the surface waters, the remaining two focus on the groundwater. The first paper of Kadłubowski et al. describes the rainfall/snowmelt-runoff model for the Upper Narew River basin. This model is a part of the Integrated Hydrological Monitoring and Forecasting System for the Vistula River Basin. The idea of the model and the main procedures are described. The second paper of Piniewski and Okruszko describes the application of the hydrological component of the catchment model, Soil and Water Assessment Tool (SWAT) in the whole Narew basin. The main objective was to perform a multi-site calibration and validation of SWAT using daily observed flows from 23 gauging stations as well as to assess the model's capability to perform reliable simulations at spatial scales that were smaller than in the calibration phase. Porretta-Brandyk et al. in the third paper deal with the Upper Basin of the Biebrza River. For the catchment areas of two small tributaries WetSpa model was applied for runoff simulation based on soil-atmosphere-plant mass balance at a catchment scale. The simulated hydrological processes included: precipitation, evapotranspiration, plant canopy interception, soil interception, infiltration and capillary rise, ground water flow. The last paper in this group (Banaszuk et al) analyses the subcatchment inflow using End-Member Mixing Analysis (EMMA). The authors identify flow paths and source areas controlling river chemistry during a snow melt induced spring high flow event. EMMA using Ca^{2+}, Mg^{2+}, Cl^{-}, and H^{+} showed that stream chemistry could be explained as a three-component mixture of overland flow, shallow groundwater and soil solution from arable soils along the stream margin and deeper groundwater. The temporal variability in the flow pathways and solute sources during snowmelt were explained.

The next two papers deal with the groundwater models: one in the watershed area; second in the groundwater fed mired named Red Bog. The main goal of the first paper (Mioduszewski et al.) is to explore by hydrological modeling the groundwater system on both sides of the watershed boundary between the rivers Narew and Supraśl and the influence of two nearby peat mines. An integrated model of the area was set up using the SIMGRO program. The aim of the model simulations was to estimate the historic hydrological situation of the area. In the second paper of Grygoruk et al, a three dimensional finite-difference steady-state groundwater model was applied to analyze the groundwater flow system of the Middle Biebrza Basin. The study contains analysis of hydrogeological and morphological outline of the area, as well as the description of developed groundwater model including conceptual model description, model calibration and sensitivity analysis of parameters.

The last two papers focus on surface water management issues using the hydrodynamic models for the Upper Narew valley. Kiczko and Napiórkowski present a Multiple Criteria Decision Support System (DSS), based on the Aspiration Reservation method, for the optimal management of the Siemianówka reservoir. The proposed DSS makes it possible to find a trade-off between different reservoir goals, such as: agriculture, fisheries, energy production and wetland ecosystems. The control problem is solved using Receding Horizon Optimal Control Technique. Kubrak et al. analyze the results of the dam break wave forecast in the valley of the Narew River, after the failure of the Siemianówka Reservoir earth dam, are presented. The velocity of the wave-front propagation in the Narew Valley and discharge characteristics as well as the inundation areas are calculated using 1-D hydrodynamic model.

In our view, the papers in the present volume of Geoplanet once again support the notion that only the cooperation of experts from different modeling groups can increase the quality of models and find the gaps in our understanding of hydrological processes.

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Tomasz Okruszko

Contents

Operational Rainfall/Snowmelt-Runoff Model for Upper Narew River

Andrzej Kadłubowski, Małgorzata Mierkiewicz and Halina Budzyńska

Abstract This paper presents results of the rainfall/snowmelt-runoff model for the Upper Narew River basin. This model is a part of the Integrated Hydrological Monitoring and Forecasting System for the Vistula River Basin. The idea of the model and main procedures are described. Several remarks and experiences of the calibration process are presented.

1 Introduction

In 1996 the Institute of Meteorology and Water Management in Warsaw (IMGW) and the Swedish Meteorological and Hydrological Institute in Norrköping, Sweden (SMHI) started to co-operate in the project Integrated Hydrological Monitoring and Forecasting System (IHMS) for the Vistula River Basin (Mierkiewicz et al. 1999). The System was developed based on the Swedish rainfall/snowmelt-runoff model, HBV and the flow routing hydrodynamic model, HD, in use at the Polish Institute (Lindel et al. 1997). During few months the System was developed for the lower and middle Vistula river basin and finally it was applied in the operational hydrological service at the IMGW.

Main tributaries or their upper parts were modeled by the HBV model. This model was also set-up and calibrated for the Upper Narew River.

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2 Rainfall/Snowmelt-Runoff Model HBV

Originally the rainfall-runoff model HBV was developed for runoff simulations and hydrological forecasting in the early seventies [for inflow forecasting to hydropower reservoirs in Scandinavian catchments (Berström 1976)]. It is characterized as a semidistributed conceptual model with moderate demands on input data. The model is usually run with daily values of rainfall and air temperature and monthly estimates of potential evapotranspiration. The model components clearly represent individual hydrological processes. It contains routines for snow accumulation and melting, soil moisture calculation, runoff generation and a simple routing procedure (Fig. 1). The catchment can be divided into sub-basins. Each subbasin is then divided into zones according to altitude, lake area and vegetation.

2.1 Main Procedures of the HBV Model

2.1.1 Snowmelt and Accumulation

Snowmelt is calculated separately for each elevation and vegetation zone according to the degree-day equation:

$$Q_m(t) = \mathrm{CFMAX} \cdot (T(t) - TT) \tag{1}$$

where Q_m, snowmelt; CFMAX, degree-day factor; T, zone temperature; TT, temperature limit for snow/rain.

The threshold temperature is usually used to decide whether precipitation is rainfall or snowfall. It is possible to have different threshold for accumulation and melting. It is also possible to use a threshold interval for a rain and snow mix.

Because of the porosity of the snow some rain and meltwater can be retained in the pores. A retention capacity of 10% of the snowpack water equivalent is assumed in the model. Only after the retention capacity has filled, meltwater will be released from the snow. The snow routine also has a general snowfall correction factor which adjusts for systematic errors in calculated snowfall and winter evaporation.

2.1.2 Soil Moisture

The soil moisture routine is the main part controlling runoff formation. Soil moisture dynamics are calculated separately for each elevation and vegetation zone. The rate of discharge of excess water from the soil is related to the precipitation and the relationship depends upon the computed soil moisture storage, the maximum soil moisture content (FC) and the empirical parameter BETA, as