SIMULATION OF DAILY RUNOFF FOR THE SALACA RIVER BASIN

Elga Apsīte and Anda Bakute

University of Latvia, Faculty of Geography and Earth Sciences,
Raiņa bulv. 19, Rīga LV-1586, Latvia, E-mail: elga.apsite@lu.lv

ABSTRACT

The Salaca River basin is the fifth largest in Latvia. The total drainage area of the river basin is 3421 km^2 where the Burtnieks Lake watershed occupies 62%. In Latvia, the conceptual model METQ for the simulation of hydrological processes of the different size catchments was applied over ten years. In this study, the last version METQ2007BDOPT of the conceptual rainfall-runoff METQ model simulating the daily runoff was applied. The model structure and parameters were basically the same as in the METQ98, with some additional improvements and semi-automatic calibration performance. The preliminary results of calibration showed a good coincidence between the measured and simulated daily discharges. The Nach-Sutcliffe efficiency R^2 varies from 0.76 to 0.51 and correlation coefficient r from 0.88 to 0.75 for the four sub-basins of the River Salaca with thirty and twelve years calibration period from 1961 to 1990.

Keywords: simulation of runoff, conceptual rainfall-runoff model, river basin, Latvia

INTRODUCTION

In the modern hydrology, conceptual rainfall-runoff models are widely used tools. One of the advantages is that models are usually simple and relatively easy to use (Bergström, 1991; Bergström et al., 1996; Uhlenbrook et al., 1999; Merz and Blöschl, 2004). Contrary to more complex, physically-based, widespread models such as the SHE model (Abbott et al., 1986), the required input data are readily available for most applications (Seibert, 1999; Uhlenbrook et al., 1999; Beven, 2001; Zīverts and Apsīte, 2001). The applied models help to investigate and to solve different problems, i.e., in water resource management, flood forecasting, water quality or future climate change assessment.

In Latvia, during the last twenty years, several versions of mathematical models of hydrological processes have been developed – METUL (Krams and Ziverts, 1993), METQ96 (Zīverts and Jauja, 1996), METQ98 (Ziverts and Jauja, 1999), METQ2005 and METQ2006. In this paper, the modelling results of the latest version METQ2007BDOPT are presented. The METQ is a conceptual rainfall-runoff model of catchment hydrology, originally developed using Latvian catchments. The model is successfully applied to small and relatively large catchments, the Brook Vienziemīte (A=5.92 km^2) and the River Daugava (A=81,000 km^2 at the Pļaviņas HPP) respectively. Furthermore, the METQ model has been used for different hydrological tasks, for instance, to evaluate the model performance before and after drainage construction and to estimate the probable maximum flood (Ziverts and Jauja, 1999), to study eutrophication and hydrotechnical problems of lakes, including climate change effects (Bilaletdin et al., 2004; Ziverts and Apsite, 2005), and to attempt model parameter sets for ungauged catchments from measurable variables and to simulate nutrients runoff in typical agricultural river basins (Jansons et al., 2002; Apsite et al., 2005).

The aim of this study was to apply a conceptual rainfall-runoff METQ model - the latest version METQ2007BDOPT, to the Salaca River basin for the model calibration and simulation of daily runoff.

MATERIALS AND METHODS

Study site

The Salaca River basin is the fifth largest and locates in the North-East of Latvia (Fig. 1). The total drainage area of the river basin is 3421 km^2. The Lake Burtnieks is the fourth largest lake in Latvia. Its total drainage is 2215 km^2 and it occupies 62 % of the River Salaca catchment; the surface area of the lake is 40.06 km^2 and water renewal takes place 6-7 times a year. The inflowing rivers of the Lake Burtnieks are the rivers Rūja, the Seda, the Briede and twenty seven smaller rivers (Fig. 2). Three largest rivers amount for 73-75 % of the total discharge into the lake. The only outlet of the lake is the River Salaca which is 95 km long and falls into the Baltic Sea. The river is characterised by the long-term discharge - 33 m^3/s and slight slope of ~ 0.4 m/km.

The climate is temperate, cool and humid. The average temperature of a year ranges from +4.0 to +5.5 ^{o}C. The mean temperature is -5.0 ^{o}C in January and +17 ^{o}C in July. The average amount of precipitation ranges from 600 to 800 mm per year.

The study area is located mainly in the North Vidzeme Lowland. The Burtnieks Lake is situated in the lowest central part of the bedrock macrodepression. The bedrock (sub-quaternary) surface mainly consists of weakly cemented Middle Devonian sandstone of the Burtnieks Formation, in some places inter-bedded with thin siltstone and shale (Zelčs and Dreimanis, 1997). The bedrock is covered by Quaternary deposits which a thickness varies from 10 to 40 meters. The deposits are mainly glacial sediments as sand, gravel and pebble mixture, clayey sandy till and sandy clayey till, as well as glaciotectonically deformed and non-deformed sand, silt and clay. The eolian sediments are located in the lower reaches of the Rūja and the Seda river basins. In the depretions, between the drumlins, glacial sediments are covered by peat, but in river valleys - by alluvial sediments (Zelčs, 1995). The surface of the Burtnieks Plain is slightly undulating with a typical drumlin landscape.

The main types of the soil are sod-podzolic, sod-pseudogley and typical podzols in the highest parts of the landscape. There is sod-gleysolic, podzolic-gley, humus-podzolic gley and bog humus soils in depressions and alluvial soils in the river valleys and around lakes.

Agricultural land covers ~40%, forests ~ 30% and bogs - 12% of the total drainage area of the Salaca River. The largest bog areas are located in the drainage basins of the rivers Rūja and Seda, and in the right part of the Salaca basin.

During the last centuries, different management actions have been carried out in the Lake Burtnieks watershed. Water level of the lake was lowered for 1 m after the regulation measures of the River Salaca carried out in 1929. The surface area of the lake was changed from 35.49 km^2 in 1932 to 40.06 km^2 in 1992. In the 1980-ties the lake was highly eutrophic. Overgrown surface area of the lake changed from 5 % in 1952 to 20-25% in 1992 (Bilaletdin et al., 2004).

The Salaca River basin is a part of the North Vidzeme Biosphere Reserve, officially announced in 1997. In the same year the Burtnieks Lake was included into the UNESCO's Man and the Biosphere program and became a member of the UNESCO's Biosphere Research Network.

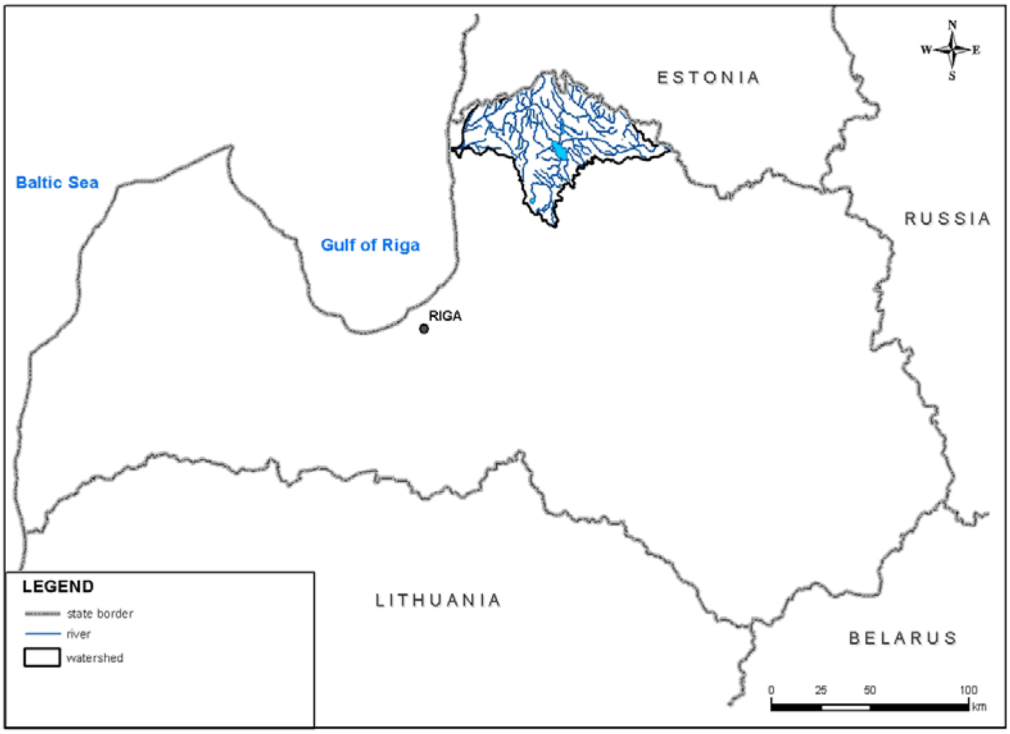

Figure 1 The locations of study catchment – the River Salaca

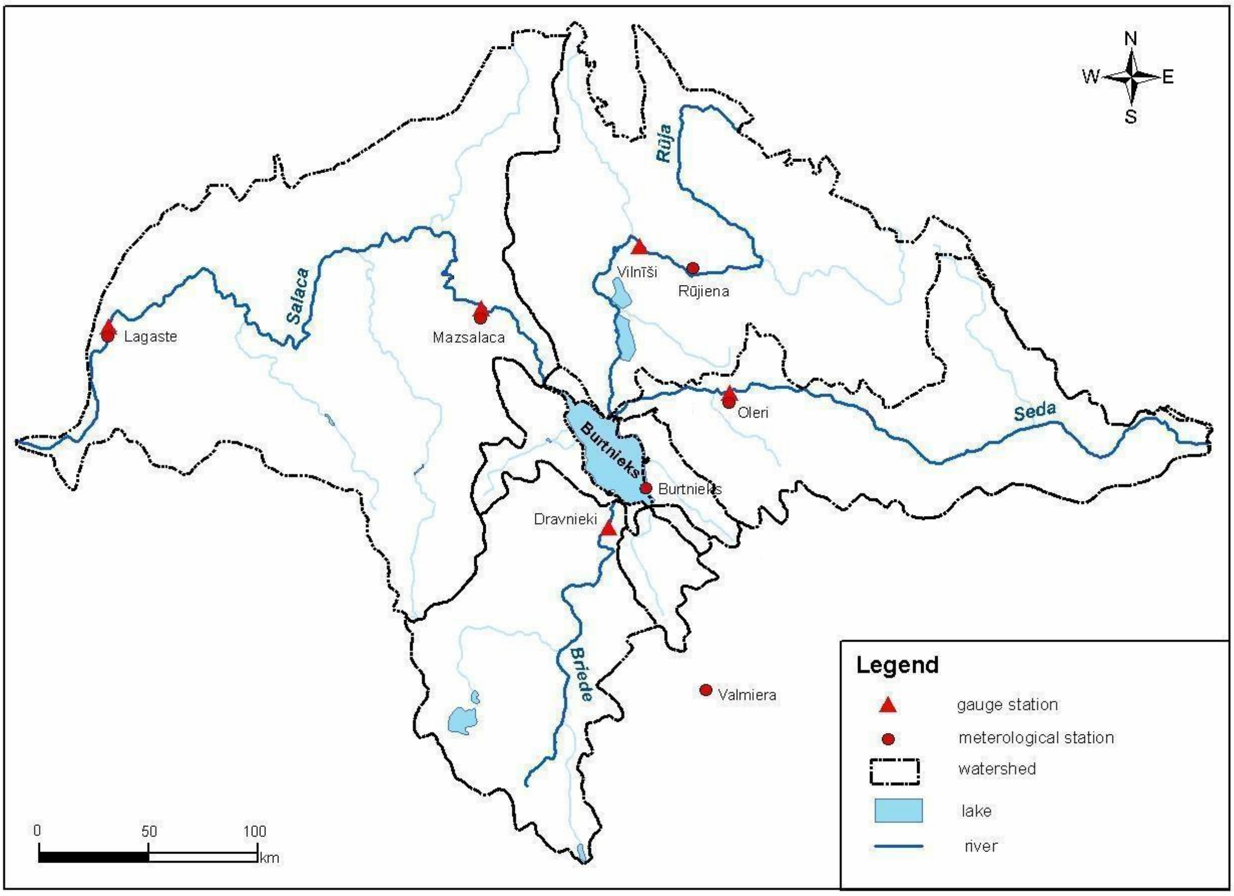

Figure 2 The locations of gauge and meteorological stations, and the sub-basins of the River Salaca catchment

The conceptual rainfall-runoff METQ model

The METQ model is a conceptual rainfall-runoff model of catchment hydrology which simulates daily discharge and evapotranspiration, using as input the following variables: daily air temperature, precipitation and vapour pressure deficit observations. The model consists of different routines representing snow accumulation and ablation, water balance in root zone, water balance in the groundwater and capillary water zone and runoff routing. Runoff routing can be simulated by simple hydrological methods, such as modifications of the unit hydrograph approach. However, if there is a lake in the river basin which considerably influences the hydrological regime of the river, then there is a need for hydraulic runoff routing. More detailed description of the model can be found in other literature sources (Ziverts and Jauja, 1996; Ziverts and Jauja, 1999). In general, the structure and simulation of hydrological processes by the METQ model are similar to the HBV (Bergström, 1976; Bergström, 1992) model developed in Sweden.

The latest version METQ2007BDOPT and its application

Similarly to previous versions of the METQ model, the latest version of applied METQ2007BDOPT is used for the simulation of the daily runoff and evapotranspiration for the rivers with different catchments areas. The model parameters are basically the same as for the METQ98 (Ziverts and Jauja, 1999). However, METQ2007BDOPT has one additional Beta parameter, providing twenty three parameters in total. The METQ2007BDOPT has semi automatic calibration performance for twelve parameters.

Daily meteorological data of six meteorological stations were used as input data for the METQ2007BDOPT model. Measurements of air temperature, precipitation and vapour pressure deficit were used for preparing the climatic data series. For the model calibration, time series of daily river discharge of four gauge stations were applied. The calibration period was selected from 1961 to 1990 (as the control climate) with the aim to simulate the future scenario climate from 2071 to 2100. The locations of meteorological and gauge stations are showed in Figure 2. A statistical criterion R^2 (Nash and Sutcliffe, 1970), a correlation coefficient r and mean values were used in the analyses of model calibration results.

The Salaca River basin was divided into five sub-basins: the Salaca (1206 km^2), Rūja (992 km^2), the Seda (543 km^2), the Briede (444 km^2) and the Burtnieks (236 km^2, small rivers entering into the lake). To consider the runoff heterogeneity in the runoff processes, the studied sub-catchments were divided into hydrological response units (HRU) characterised by a relative homogeneity with the respect to the most important parameters, including slope, vegetation and soil characteristics. Catchment area was divided into six HRUs: agricultural lowlands, hilly agricultural lands, forests, swamps, lakes and sandy lowlands. The last one as an important additional geomorphologic HRU was introduced in the METQ2005, the METQ2006 and the METQ2007BDOPT versions what improved the modelling results of runoff in likely sandy catchments. The water balance and runoff of each HRU has been simulated in three storages: snow, soil moisture and groundwater. The total runoff from each HRU consists of three runoff components: Q_1 – surface runoff, Q_2 – subsurface runoff (from the groundwater upper zone) and Q_3 – base flow (from the groundwater lower zone).

RESULTS AND DISCUSSION

The data series of at least five years period from four gauge and six meteorological stations were used for the calibration of conceptual rainfall-runoff METQ2007BDOPT model for four different size sub-basins of the River Salaca catchment. We can conclude that the number of observation points and the calibration periods is sufficient for this kind of drainage areas. The results of the conceptual model calibration showed a good coincidence between the observed and simulated daily discharges: the Nach-Sutcliffe efficiency R^2 varies from 0.76 to 0.51 and correlation coefficient r – from 0.88 to 0.75. The best results of model calibration were found for the sub-basin Salaca at Lagaste (Fig. 3) R^2 – 0.88 and r – 0.76 (1961-1990) and the sub-basin Briede at Dravnieki sub-basin R^2 – 0.87 and r – 0.75 (1980-1990). A weaker coincidence between observed and simulated hydrographs was found for the sub-basin Seda at Oleri R^2 – 0.81 and r – 0.61 and for the sub-basin Rūja at Vilnīši where r is 0.75 and R^2 – 0.51 (Fig. 4). For the last two sub-basins, the available calibration period was from 1979 to 1990.

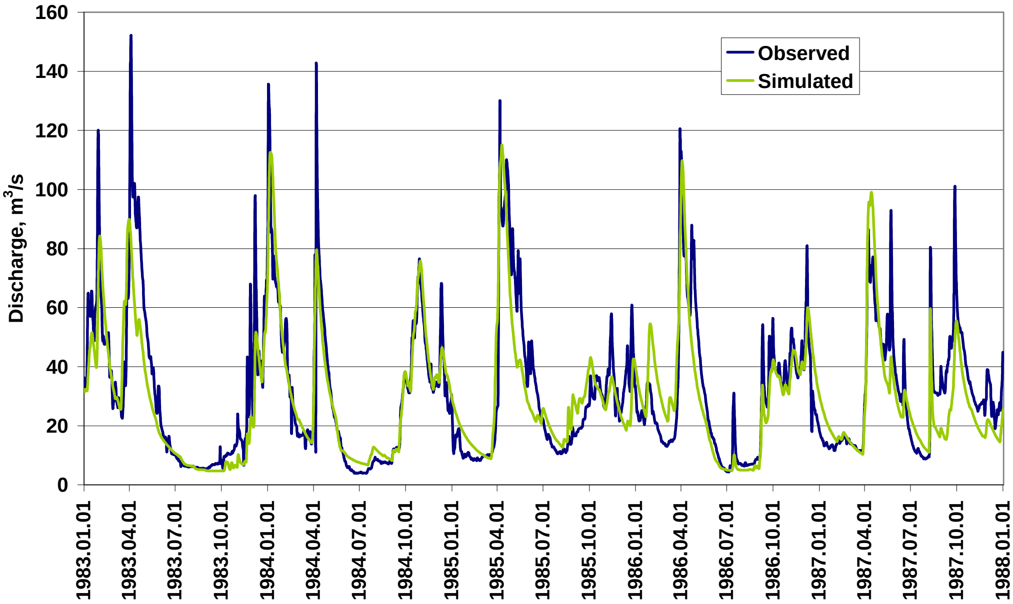

Figure 3 Observed and simulated daily discharge at runoff gauge Salaca-Lagaste

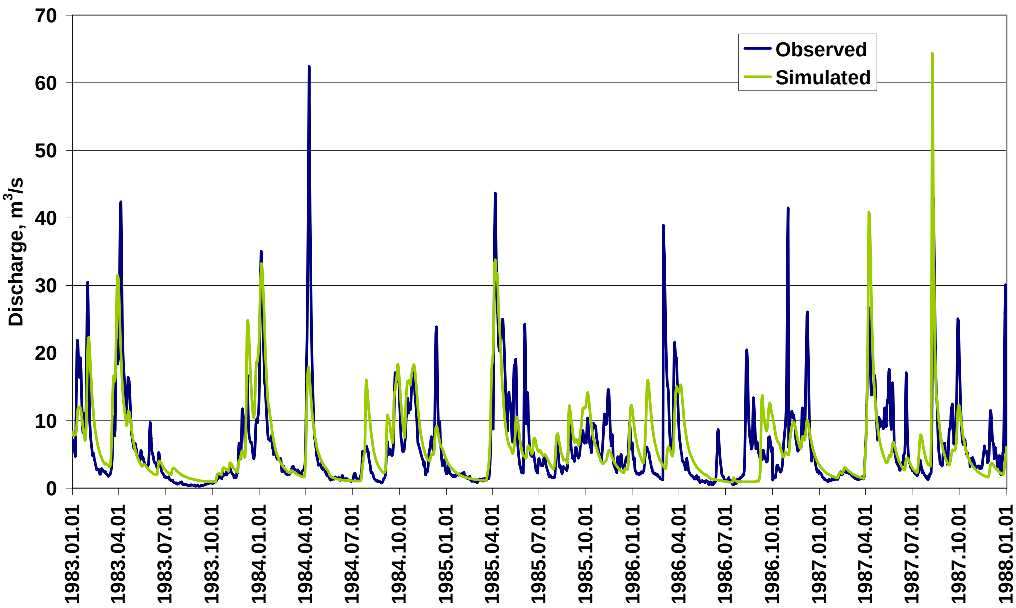

Figure 4 Observed and simulated daily discharge at runoff gauge Rūja-Vilnīši

One of the main sources of difference between the simulated and observed runoff values is the quality of precipitation input data and the location of available meteorological stations characterising the spatial and temporal distribution of precipitation in the studied drainage area. For instance, the meteorological station in Rūjiena is located in the middle part of the River Rūja basin. We assume that the model METQ2007BDOPT calibration results are not of the highest quality due to lower quality of precipitation data.

Another explanation of the above mentioned calibration differences could be a broad palufied flood plain and a high percentage of the wetlands in the drainage basins of the rivers Seda and Rūja. This reason determines the specific hydrological regime which differs from the other studied rivers and is difficult to simulate the rainfall-runoff processes without additional riverbed measurements. However, Seibert J. (1999) pointed that all many successful rainfall-runoff models are essentially very simple and for many practical purposes we do not need to include all details in developing a predictive model. In models of this kind, most parameters are not measurable but should be estimated by calibration using at least some observed runoff data.

In this study, we tried to find out the relationships between the model parameter values with semi-automatic calibration performance and physiographic sub-catchment characteristics. The studied sub-basins of the Salaca River could be divided into two groups: (I) the Rūja and the Seda, and (II) the Briede and the Salaca. The river basins of Rūja and Seda are located in the Burtnieks Plain and are characterised by a lower hypsometry, sandy and moraine areas, a high percent of bogs and flood plain in lower reaches. The Briede River basin is characterised by moraine hilly topography and bog areas. The geomorphologic condition of the sub-basin Salca, particularly the left bank part of the basin, is more similar to the River Briede basin. Some of the optimized parameters of the model were estimated considering the previous experience, for instance, water storage in root zone based on the previous studies of irrigation regime in Latvia (Ziverts and Jauja, 1999). Determination of fillabale porosity and height of capillary rise depend on the hydrophysical characteristics of most common types of soils. Height of capillary rise depends on the soil grading composition. In this case the sub-basins of Rūja and Seda are characterised by sandy areas (eolian sediments) and the parameter of capillary rise value is lower. The second group of sub-basins has higher parameter average values which are semi-automatically calibrated and describe the subsurface drainage and the drainage capacity of deeper layers. These drainage areas are characterised by hilly agricultural lands with deeper infiltration efficiency. Also, the similarity of physiographic conditions (climate, topography, soil, land-use, and geomorphology) of studied sub-basins could be found for the group of the parameters describing the surface runoff generation processes. However, the regionalization of the METQ2007BDOPT model parameters for river basins in Latvia might be another interesting issue for further research.

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ACKNOWLEDGEMENTS

This study was supported by the National Research Program *Climate change impact on water environment in Latvia* and data were provided by *Latvian Environment, Geology and Meteorology Agency* and *SIA Meliorprojekts*. Authors would like to thank also Professor Ansis Zīverts for generously provided consultations and knowledge about modelling basics.