THE IMPLEMENTATION OF THE HBV MODEL ON THE SAVA RIVER BASIN

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Abstract

The Swedish HBV model was used for modelling the Sava River discharge and modelling of snow cover over the Sava river watershed in Slovenia. The Sava River is the largest river in Slovenia and tributary of the Danube River, contributing to its largest runoff. It covers more than half of the territory of Slovenia, namely 10.700 km^2. The watershed is heterogeneous, mountainous in the upper parts and plain in the middle reach. There are also some karstic regions. The floods are caused by heavy rainfall in headwater mountain areas, especially in autumn. Some tributary flows can rise more than a hundred times in such events. For the purpose of flood forecasting the HBV model was set up for the whole watershed using the time step of 24 hours to calibrate the set of model parameters, which then used for recalibration of the model with time step of 1 hour. The watershed was divided to 26 subcatchments. Model input data are precipitation, potential evapotranspiration, and in case of climates with temperatures below zero, temperature data. Measured discharges are needed to calibrate, verify and up-date the model. Satisfactory calibration of the model was achieved, although the topography has strong influence on the meteorological happening in the catchement, especially in the upper stream of the Sava river, and small number of available raingauges.

Keywords: *HBV, modelling, runoff, Sava, precipitation, evaporation, watershed.*

1 INTRODUCTION

Following the good results using the Swedish HBV model for the simulation of runoff for the Savinja river basin (Kobold, 2007), the model was used for modelling the Sava River discharge and modelling of snow cover over the Sava river watershed in Slovenia. The Sava River is the largest river in Slovenia and tributary of the Danube River, contributing to its largest runoff. It is created by two rivers Sava Bohinjka (31 km long) and Sava Dolinka (45 km long) which join together near town of Lesce. The head part of the Sava River basin is located in Slovenia and before it reaches Danube it is 990 km long. On the way to Belgrade it flows through three European countries: Slovenia, Croatia and Serbia. At the start of its journey the Sava river has an average discharge of about 45 m^3/s (near town of Lesce), just after exiting Republic of Slovenia it has a moderate discharge of 255 m^3/s and before it joins Danube in Belgrade the discharge rises to amazing 1.722 m^3/s. Sava river watershed covers more than half of the territory of Slovenia, namely 10.700 km^2. The upper part of the basin is mountainous with altitudes up to 2800 meters. The altitudes of the plain area, in the middle reach are between 100 and 400 meters. The floods, usually flash floods, are caused by heavy rainfall in headwater mountain areas, especially in autumn. Some tributary flows can rise more than a hundred times in such events.

2 METHODS

2.1 HBV model

The HBV model was originally developed at the Swedish Meteorological and Hydrological Institute (SMHI) in Norrköping, Sweden (Bergström, 1976). After twenty years, the HBV model has become a standard tool for runoff simulations in the Nordic countries, and the number of applications in other countries is growing. The HBV approach has since the early days proved flexible and robust in solving water resource problems and applications. It is characterised as a conceptual model. The aim of the first operational applications of the HBV model was hydrological forecasting. Since then, the field of applications has widened and covers today real-time forecasting, control of data quality, extension of runoff records and filling in of gaps, design floods, synoptic water balance mapping, water balance studies, simulations of the effects of a changing climate and simulations of groundwater response.

The model consists of several fundamental hydrological routines, including a snow routine based on a degree-day relation, and a soil moisture routine that accounts for soil field capacity and changes in soil moisture storage due to rainfall/snow melt and evapotranspiration. The runoff generation routine transforms water from the soil moisture zone to runoff.

The snow routine of the model controls snow accumulation and melting. It works separately for each elevation and vegetation zone. The snow routine is based on a simple degree-day relation. The precipitation is assumed to accumulate as snow when the air temperature drops below a threshold value which is usually close to 0°C. Melting starts with temperatures above the threshold. The threshold temperature is normally used to decide whether the precipitation falls as rain or snow, but it is possible to have different thresholds. It can also be extended to an interval and within this interval precipitation is assumed to be a mix of rain and snow (decreasing linearly from 100 % snow at the lower end to 0 % at the upper end). The snow pack is assumed to retain melted water as long as the amount does not exceed a certain fraction of the snow. Then, runoff is generated. When temperature decreases below threshhold temperature, this water refreezes. The temperature is an important parameter in snow routine and it is altitude corrected by applying altitude correction parameter.

The soil moisture accounting routine computes an index of the wetness of the entire basin and integrates interception and soil moisture storage. It is the main part controlling runoff formation. This routine is based on the three main parameters BETA, LP and FC. FC is the maximum soil moisture storage in the basin. BETA controls the increase in soil moisture storage from each millimetre of rainfall or snow melt at a given soil moisture deficit. LP is a soil moisture value above which evapotranspiration reaches its potential value, which means that it controls the shape of the reduction curve for potential evapotranspiration. At soil moisture values below LP, the actual evapotranspiration will be reduced. The parameter LP is given as a fraction of FC. The effect of the curve determining runoff generation is that the response is gradually increasing with decreasing wetness.

The runoff generation routine is the response function which transforms excess water from the soil moisture zone to runoff. It also includes the effect of direct precipitation and evaporation on a part which represents lakes, rivers and other wet areas. The function consists of one upper, non-linear, and one lower, linear, reservoir. These are the origins of the quick and slow runoff components of the hydrograph. The yield from the soil moisture zone, i.e. the effective precipitation, will be added to the storage in the upper reservoir. As long as there is water in the upper reservoir, water will percolate to the lower reservoir. At high yield from the soil, percolation is not sufficient to keep the upper reservoir empty, and the generated discharge will have a contribution directly from the upper reservoir, which represents drainage, through more superficial channels. The lower reservoir, on the other hand, represents the groundwater storage of the catchment contributing to the base flow. In the latest version of the model (HBV-96), the recession is modelled by a function corresponding to a continuously increasing recession coefficient. Each one of the subbasins has individual soil moisture accounting procedures and response functions. The runoff is generated independently from each one of the subbasins and is then routed through a transformation function in order to get a proper shape of the hydrograph.

The flexible structure of the IHMS/HBV system allows the model to make necessary sub-divisions with respect to different climate zones, land-use, density of the hydrometeorological network etc. The HBV can be applied to catchments of virtually any size, from less than 1 km^2 to several hundred thousand km^2. Larger river watershed is divided into subbasins, which are also its primary hydrological units. The model is set up separately for each subbasin. Subbasins are linked together and the outflow from the upstream ones is routed through the downstream ones. The SMHI version of the HBV model is usually run with 24 hour (day) time steps, but it is possible to use shorter time steps down to 1 (one) hour, if higher resolution data is available.

Model input data is precipitation, values of potential evapotranspiration, e.g. standard monthly values and in case of climates with temperatures below zero, temperature data. The specified input potential evapotranspiration values can be corrected for altitude by using the lapse parameter which works similar to precipitation altitude correction parameter but decreases high altitude values instead of increasing them. If no evapotranspiration data is present, the values can be calculated directly from temperature data.

Measured stream-flow or reservoir inflow is needed to calibrate, verify and up-date the model. Standard model outputs are discharge/ streamflow/reservoir inflow, additionally the basin average temperature, precipitation, evapotranspitation, soil-moisture content and snow-pack are calculated. Most of those values can also, optional, be presented for all land-use types in all elevation zones.

As is the case in all conceptual hydrological models, the HBV model can be sensitive to calibration of parameters, and more or less the same result can be obtained using different parameter-sets. The model is usually calibrated by a manual procedure with set of model parameters that are changed during calibration process until an acceptable agreement with observations is obtained. The basins are computed in the order of the streamflow, so downstream basins require computed data from the upstream ones. As a result, the calibration cannot be made in the order of the subbasins the user wants. It has to follow the natural stream and flow of the river.

The number of parameters normally used in the model is in the order of 20 - 25. While 5 of them are in most cases set to standard values, some 10 are very important to calibrate. The importance of a long enough period of historical data to allow calibration, and then verification on an independent period must be taken into account when using this kind of models. Three main criteria of fit are used: visual inspection of the computed and observed hydrographs, Nash/Sutcliffe criterion R^2 and inspection of accumulated error. R^2 efficiency criterion was introduced by Nash and Sutcliffe (1970) and is commonly used in hydrological modelling. R^2 has a value of 1,0 if the simulation and the observations agree completely and 0 if the model does not perform any better than the mean value of the runoff record, but in practice values between 0,8 and 0,95 (IHMS, 1999) can be achieved if the quality of observed data is good. Negative values can be the result of poor model performance or poor data. Accumulated error is another important indicator of performance. A perfect match between recorded and computed runoff would result in a straight line with a constant value of zero.

2.2 Implementation of the HBV model on the Sava river basin

The division of the Sava river basin was made to 26 watersheds with area ranging from 0,26 km^2 to 1.019,85 km^2 and further to elevation zones. The upper part of the basin is mountainous and subbasins in that area were divided in up to 5 (five) elevation zones. Subbasins in the plain area of the Sava basin, where altitudes reach maximum 400 meters, have only 1 (one) elevation zone. Each elevation zone was then divided in to two parts according to land use, so called vegetation zones (forest and field).

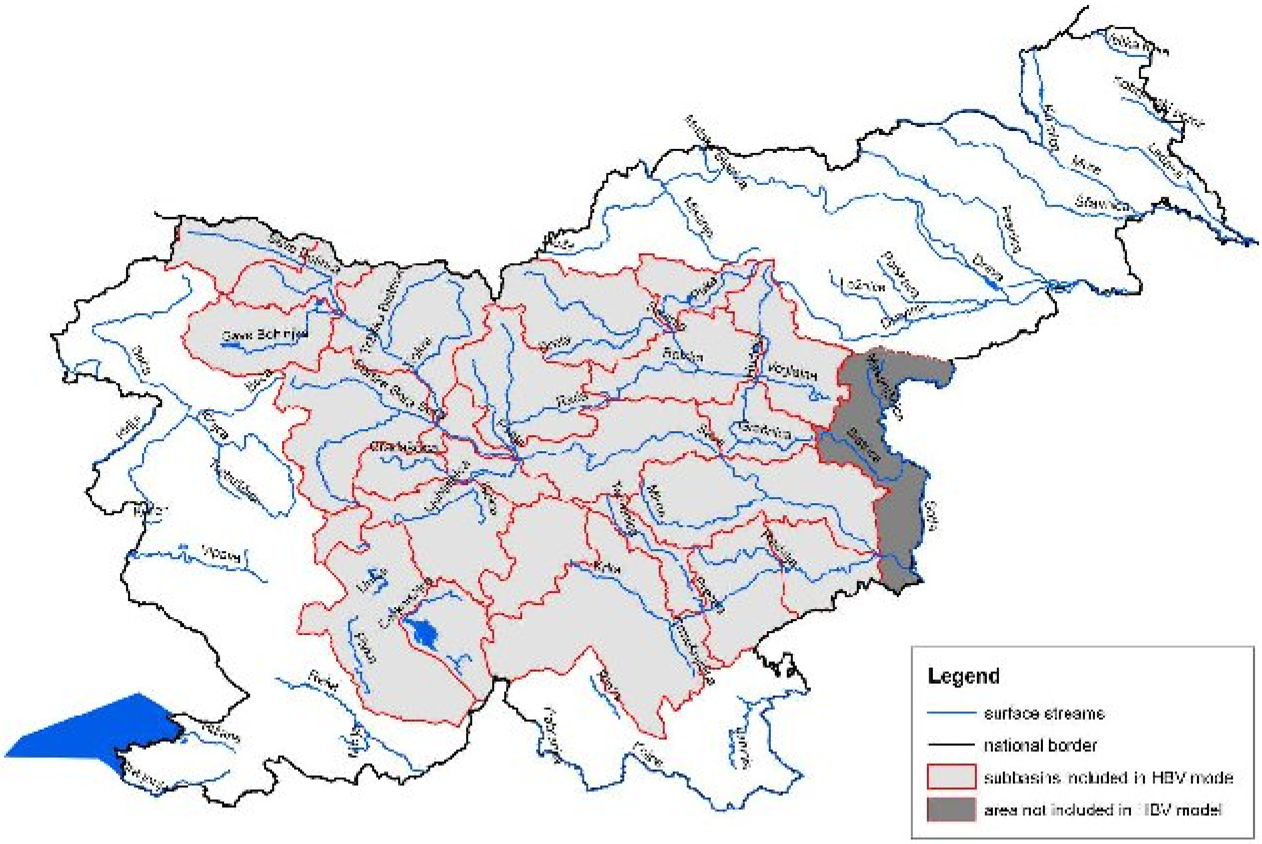


Figure 1. Slovenia, Sava river basin (grey) divided in to 26 watersheds (coloured in light grey) and the area which is not included in the modelling. (coloured in dark grey).

First the model with 24 hour (1 day) time step was set up. For this model the data was collected for the period from 1 January 1990 to 31 December 2006. Data from 1990 to 1999 was used for calibration to determine the values of a number of free parameters and data from 2000 to 2006 was used for validating the model. After the model with 24 hour time step was calibrated, it was recalibrated with time step of 1 hour. From the set of nearly 30 parameters six parameters for each subbasin was needed to be recalibrated. The remaining parameters kept the values from the 24 hour time step model. Data for the model with 1 hour time step was collected for the period from 1 January 1998 to 31 December 1999. Data was used only for calibrating the model and because of the huge amount of missing data no validation period was chosen. In spite of some difficulties with incomplete data sets, effects of the hydropower plants and wrong measurments, calibration of both models was successful.

Except for the discharge stations, missing station data sets in both models were substituted by the data sets from nearby station and corrected by correlation factor.

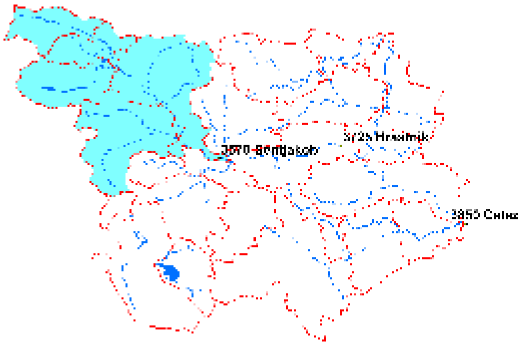
The effects of hydropower plants are best seen on figure 3 in 1 hour time step model. It takes one or two hours between the moment the hydropower plant takes the water from the Sava river and the moment it releases it. This explains the daily and especially hourly fluctuation that we can notice on the hydrographs (figure 3, figure 4). The model is unable to predict this behaviour of the discharge, unless the data of regulation schedule is fed into the model. This was not the aim of the present work. Consequently, the model gives lower R^2 values for 1-hour model (table 1), especially for upper part of the Sava river wateshed where hydropower plants are located.

A number of 7 temperature and 5 evapotranspiration stations was used in both models. In the model with 1 hour time step from 53 (used in 24 hour model) precipitation stations only 16 precipitation stations were used providing high resolution data, the rest of 37 are classical raingauge station with daily precipitation data. Weight of each station was estimated by the Thiessen method. The results are snown for 3 discharge measuring stations.

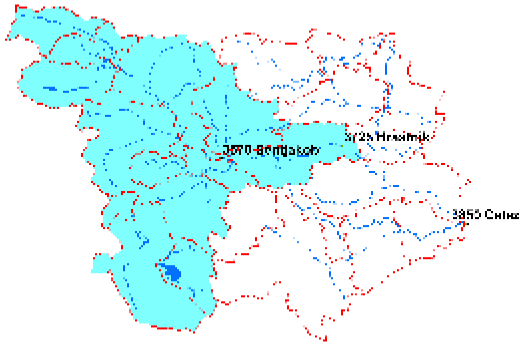
All the data used during calibration and validation of the model (precipitation, temperature, discharge and evapotranspiration) were obtained from the station network of the Environmental Agency of the Republic of Slovenia (ARSO).

3 RESULTS AND DISCUSSION

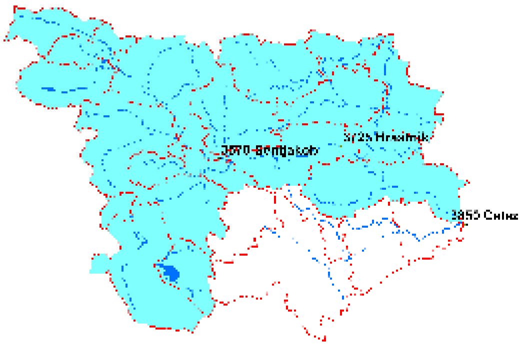
Results of calibration for two models for the Sava watershed with daily and hourly time steps can be presented in the form of hydrographs for each subbasin as well for the whole watershed, but because of great number of subbasins (26) the results are presented only for four different drainage areas as seen in Figure 4.



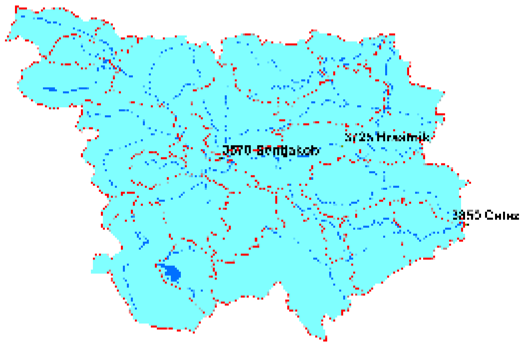
drainage area 1



drainage area 2



drainage area 3

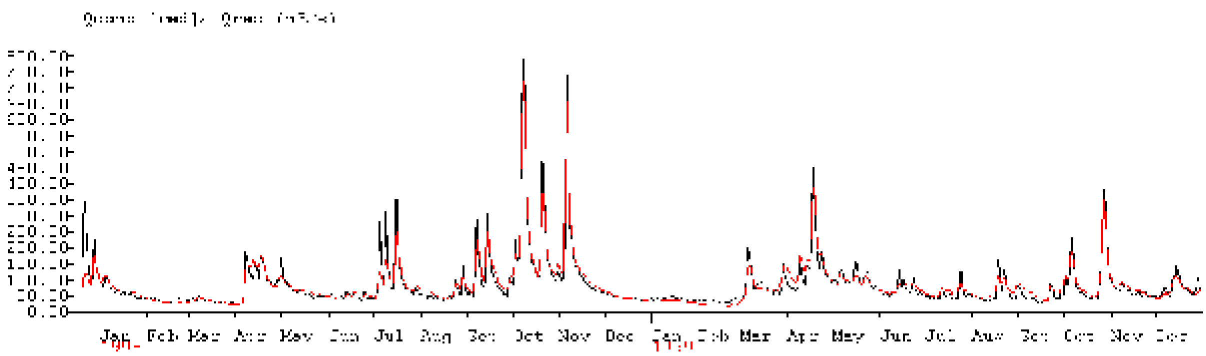


Drainage area 4

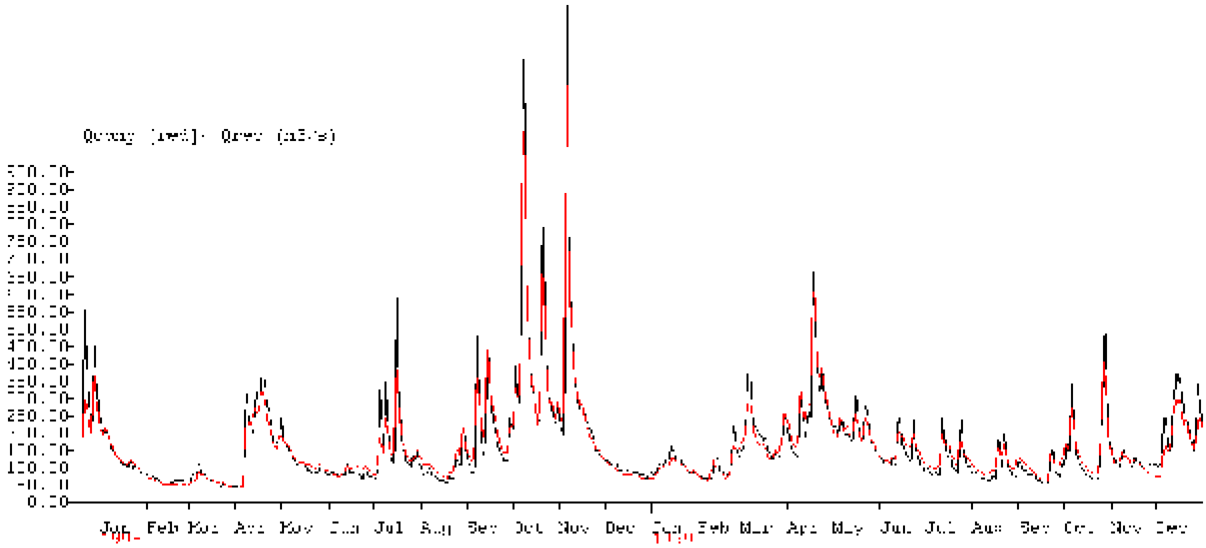
Figure 2. Modelled Sava river basin, divided in to 26 watersheds, with marked 4 different drainage area (coloured in cyan), for which results in form of hydrographs are presented.

Hydrographs for the 24-hour model, for different drainage areas are presented in Figure 3. Due to better presentation the results of calibration are not given for the whole period, but only from January 1998 to December 1999 and contain data from the flood in October 1998 (peaks seen in Figure 3). Hydrographs for 1-hour model, for the same drainage areas, are presented for the period from February to June 1998.

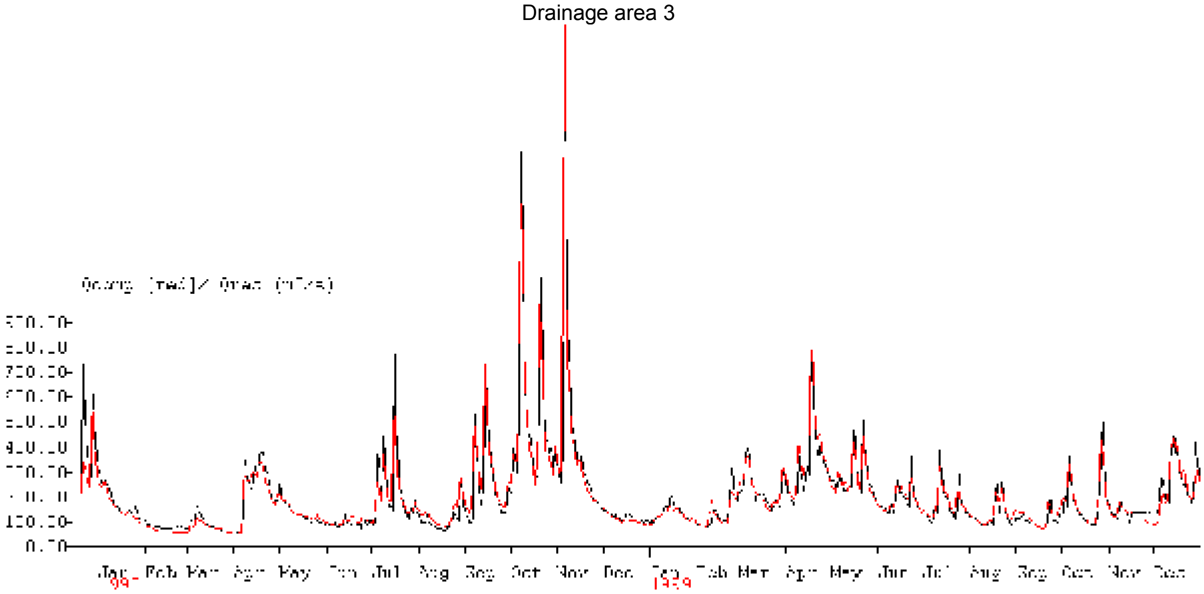
Drainage area 1



Drainage area 2



Drainage area 3



Drainage area 4

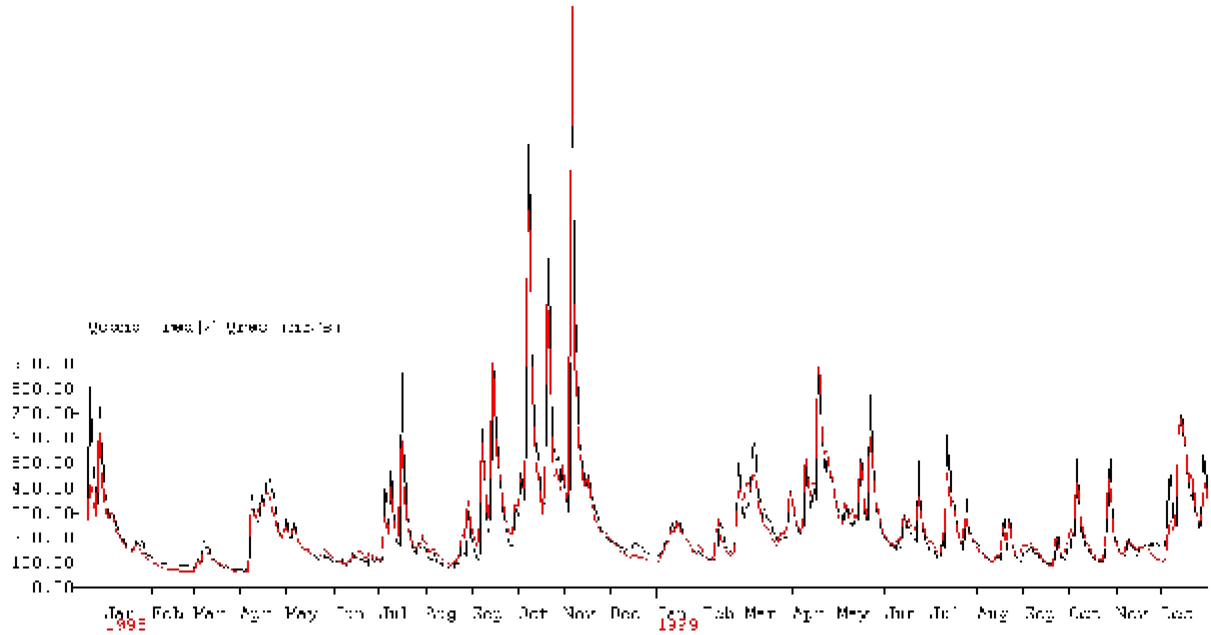
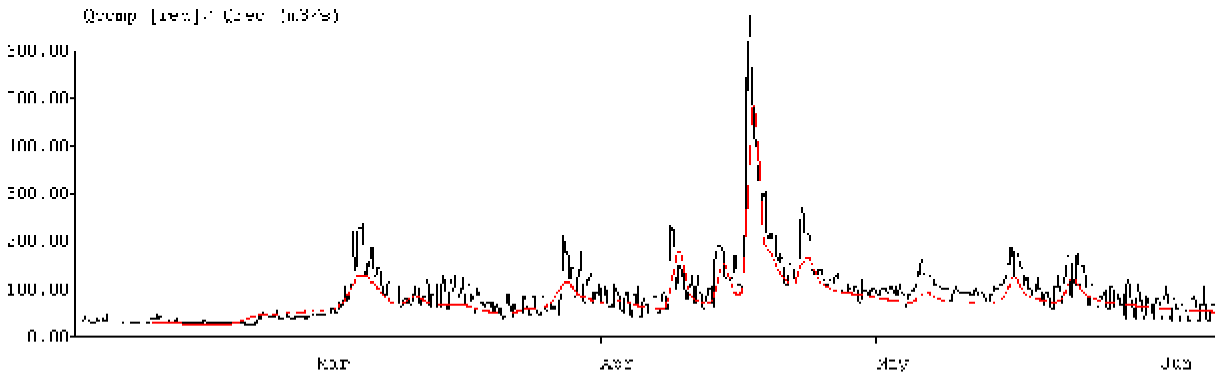
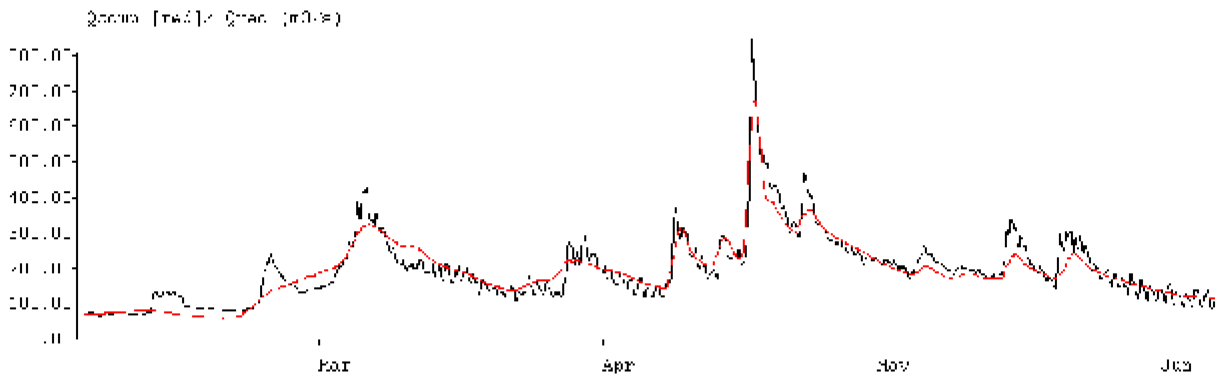


Figure 3: The comparison of recorded (Qrec) and computed (Qcomp [red]) discharges for four different drainage areas (Figure 2) from the 24-hour model.

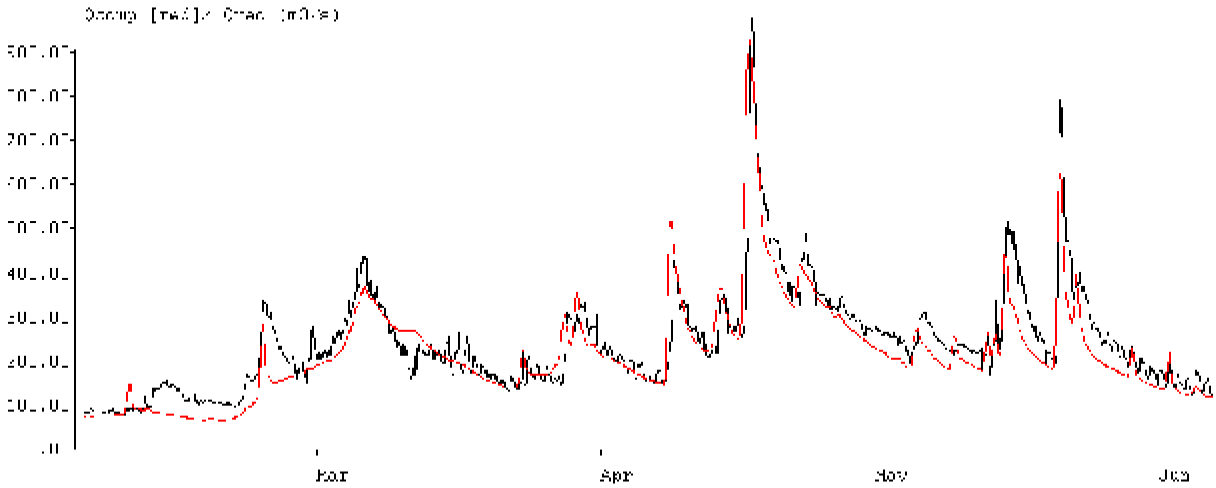
Drainage area 1



Drainage area 2



Drainage area 3



Drainage area 4

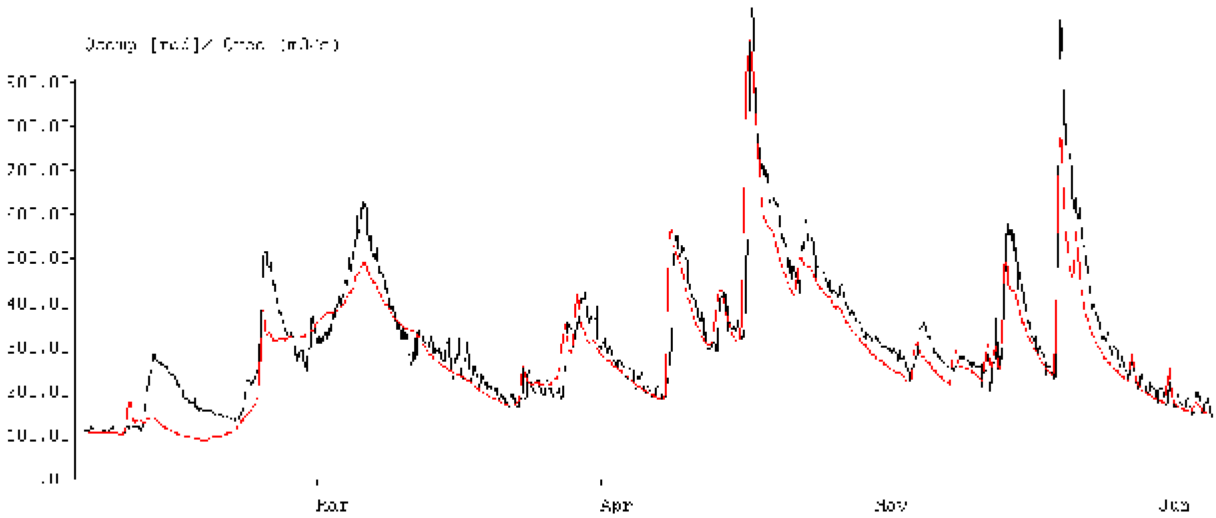


Figure 4: The comparison of recorded (Qrec) and computed (Qcomp [red]) discharges for four different drainage areas (Figure 2) from the 1-hour model.

The Nash/Sutcliffe criterion R^2, ranging from 0 to 1, was calculated for each subbasin (a value 1 represents the perfect performance). The result of present calibration is ranging from 0,644 to 0,898. It shows very good agreement between the recorded and computed discharges. The results of verification of the 24-hour model showed that the error was just slightly higher comparing with the calibration period with R^2 between 0,87 and 0,90.

Table 1: comparison of R^2 values for both models

	24 hour timestep model		1 hour timestep model
	Calibration period	Validation period	Calibration period
Drainage area	R^2	R^2	R^2
1	0,89825	0,87905	0,64379
2	0,89749	0,90322	0,87061
3	0,86652	0,86942	0,83800
4	0,88410	0,87368	0,86132

Analysis indicated that the lack of input precipitation data caused the poor result of calibration for some subbasins. To make the model more accurate, the number of precipitation and other stations should be increased (especially for 1-hour time step model). However, the additional stations are possible to add into the model after calibration process, but the model has then to be recalibrated in order to get useful results.

4 CONCLUSION AND FURTHER USE OF THE MODEL

The results of calibration of two models for the Sava river basin with two different time steps, day and hour, are presented in this article. The model with timestep of one day was initially set up for easier designing (calibrating) of the 1-hour time step model (only 5 calibration parameters needed to be recalibrated), although the model can also be used for further studying of calibration parameters, water balance studies, simulations of the effects of a changing climate, filling in the missing input data sets, etc. The model with time step of one hour is much more suitable for real time flood forecasting or designing than the 24-hour timestep model. Only 16 recording raingauges used in one hour timestep model on the catchment of 10.098,49 km^2 and its closeness is not sufficient for accurate estimation of areal precipitation. Additional input is needed to get even more reliable river runoff output. The number of raingauges is namely crucial for the estimation of areal precipitation. Small number of raingauges leads to the deviation of runoff from observed values. Analyses show great deviations especially by small amount of precipitation on the catchment when there is storm and usually local precipitation (Kobold, 2007). The analysis of number of raingauges on the areal estimation of precipitation on Savinja river subbasin (Kobold, 2007) has shown, that relative error can exceed 100 % in the case of small amount of precipitation. The relative error is smaller by precipitation causing high waters and floods and can reach 50 %. The correction of precipitation in the HBV model for some high water events showed that simulated runoff fits with measured one well by the proper precipitation input (Kobold, 2007). Satisfactory calibration of the model was achieved, although the topography of the catchement has strong influence on the meteorological happening, especially in the upper stream of the Sava river, and small number of included raingauges.
The model with one hour time step was further used for simulating discharges in more than 17 different rainfall scenarious, including scenarious with summer and autumn rainfall, heavy rainfall with moving velocity of 60 km/h, rainfall with intermediate dry period (example: 30 % probable maximum precipitation + 3 day dry period + 100 % probable maximum precipitation) and scenarious with snowmelt in connection with heavy summer rainfall.

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