Hydrological modelling: River runoff modelling of large River basins in Estonia.

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INTRODUCTION

- In recent times there has been a extraordinary development of the hydrological models which can be used as a tool to evaluate the basin's response under different conditions.
- Hydrological rainfall-runoff models so often require a calibration and validation to achieve the adequate representation of the study area. This is only possible for gauged basins, where the data are available. There are many basins for which there are not monitoring discharge data, it makes quite difficult the modelling but this disadvantage can be minimized extrapolating model parameters obtained through calibration of gauged basins to ungauged basins to simulate runoff.
- The Soil Water Assessment Tool (SWAT) used in this study is a basin-scale, continuous time model that operates on a daily time step, developed by the U.S Department of Agriculture USDA-ARS and Texas A & M University in early 1990s. It allows to simulate the integrated water cycle and predicts the impact in the medium to long term of diffuse pollution sources. The model also includes additional routines to quantify the outflow, sediments, nutrients and pesticides routed to the main gages in each sub-basin.
- Among the various possibilities offered by the SWAT model, in this particular study of Pärnu and Emajõgi Rivers, we will focus on the hydrological component of the model.

STUDY AREA AND DATA SET

- Estonia is small and friendly European country located in northeastern Europe on the edge of the Baltic sea and has a total area of 45.215 km2 .
- Pärnu river basin is situated in Western Estonia and is one of the longest rivers in the country and drains to the Bay of Pärnu, which is located at the Northern part of the Gulf of Riga in the Baltic sea. The most bigger tributaries of Pärnu river are Halliste River, Navesti River, Raudna River, Reiu River and Sauga River. It's total area is 6690 km2 and the Pärnu river length is about 144 km.
- Emajõgi River is 218 km long and the catchment area together with the river basin of Lake Võrtsjärv is 9960 km2 . The river source in the lake Pühajärv and for the first 82 km of its course, before it passes through the lake Vortsjärv, it is known as the Väike-Emajógi; below the lake, for the last 101 km of its course, the river is called the Suur-Emajógi and flows into Lake Peipsi after crossing the city of Tartu.
- Both River basins are covered mainly by forest and agricultural landscapes, most of the land is considered flat under 5 percent of slope and the hydrologic soils are mainly well drained to moderately drained. The climate of this region follows the pattern of Northern regions of Europe with an annual average temperature of about 4,3 °C and 6,5 °C, but the temperature usually falls down to negative centigrade during winter . Total annual average precipitation is 550– 750 mm with an evapotranspiration rate of 420 mm annually.
- The setup of the model requires specific information about weather sources, daily max and min air temperature and precipitation recorded at the Estonian meteorological network, topography (DEM Digital Elevation Model), soil characteristics and land use (Corine Land Cover map and Soil map of Estonia) and hydrological data (discharge measurements). Although stream-flow measurements are not necessary as an input to run the model. It will be necessary during the calibration period. The data availability and quality of the inputs can increase the accuracy of the model.

OBJECTIVES

- The aim of the present study was to implement, calibrate and validate the hydrological model to simulate the spring peak runoff, in gauged and ungauged basins of Pärnu River and Emajõgi River with a total area of 6690 km2 and 9960 km2 respectively

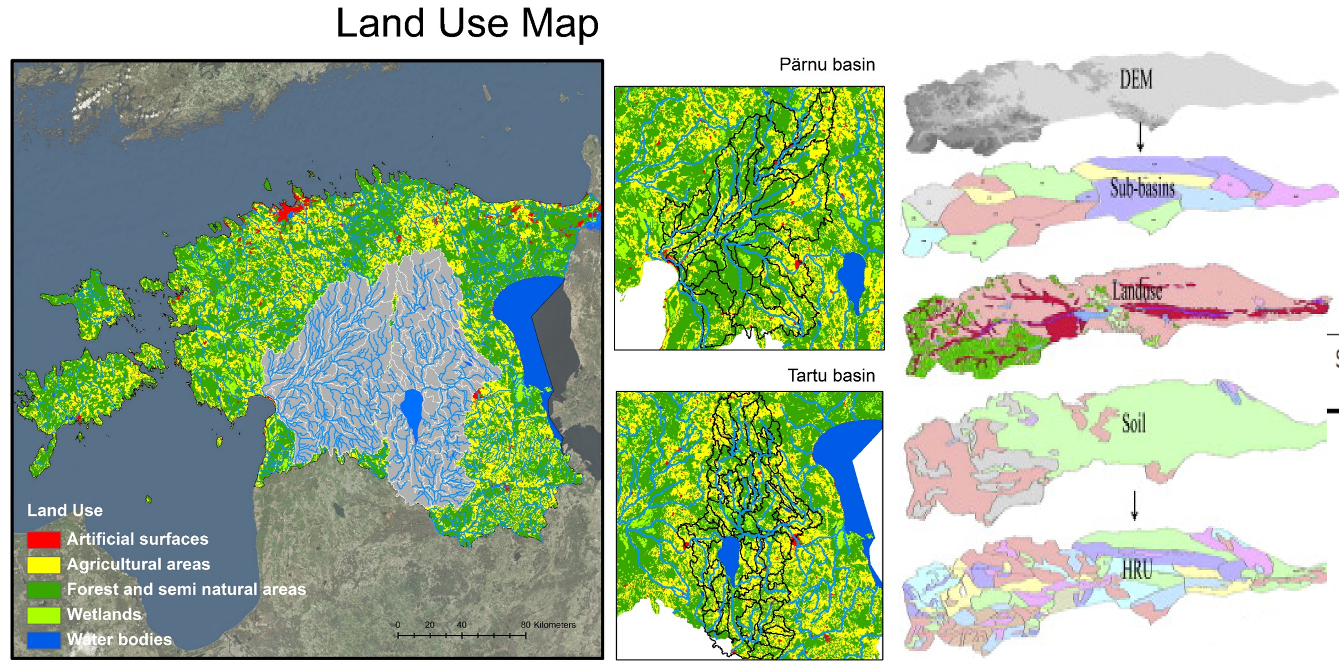
METHODS

- The calculation of the water balance is carried out on individuals units (Hydrological Response Units HRUs), which represent the combination of Land cover, soil type and slope.
- The simplified equation of the water balance is summarized by the following:

$$SW_t = SW + \sum_{i=1}^{t} (R_i - Q_i - ET_i - P_i - QR_i)$$

- Where SWt= is the final Soil water content, SW is the initial soil water content, i= Time in days of simulation period t, R= daily precipitation, Q= Runoff, ET= real evapotranspiration, P= Percolation, QR= Return Flow or baseflow.
- The model classifies precipitation as rain or snow by the mean daily air temperature. If the mean daily air temperature is less than the boundary temp, them the precipitation is classified as snow. For calculations of snow melt the model use the degree-day factor, that indicates the decreases of the water content in the snow cover caused by 1 degree above the freezing in 24 hours.
- Surface runoff was estimated by the SCS Curve Number (SCS-CN) method from daily precipitation records using default parameters values provided in SWAT, which were defined based on land use and soil data in the study area of Pärnu and Emajõgi River. SCS curve number method calculates runoff by subtracting abstractions.
- Three options are offered in SWAT for estimating potential ET: Hargreaves (Hargreaves and Samani 1985), Priestley-Taylor (Priestley and Taylor 1972), and Penman-Monteith (Monteith 1965).The potential evapotranspiration was computed using Hargreaves method based on observed daily air temperature data. Hargreaves method was used as it requires only temperature data, in contrast to the more extensive data requirements methods such as Priestley–Taylor and Penman–Monteith. The computed runoff from each sub basin, was routed through the river network to the main basin outlet by using the Muskingum method
- Model performance was evaluated using the Nash-Sutcliffe coefficient and Regression Coefficient was also used during the calibration and validation period.

Land Use Map



Statistical Evaluation Criteria	Equation
Nash and Sutcliffe efficiency	$NSE = 1 - \frac{\sum_{i=1}^{n}(O-P)^2}{\sum_{i-n}^{n}(O-\bar{O})^2}$
Coefficient of Regression	$R^2 = \left(\frac{\sum_{i=0}^{n}(O-\bar{O})(P-\bar{P})}{[\sum_{i=0}^{n}(O-\bar{O})^2 \sum_{i=0}^{n}(P-\bar{P})^2]^{0.5}}\right)^2$

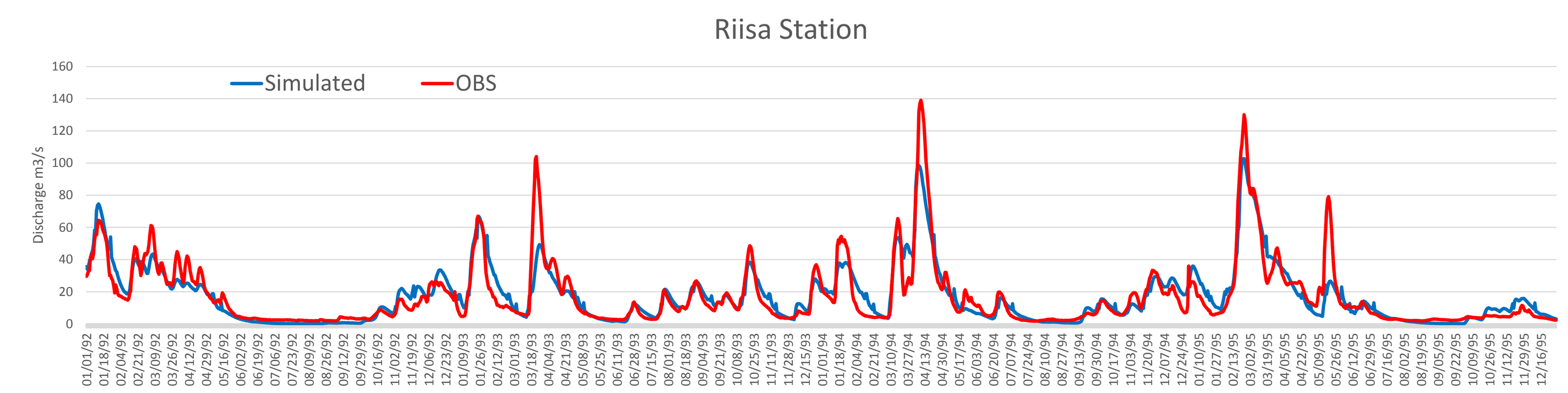
O: Measured Flow
P: Simulated Flow

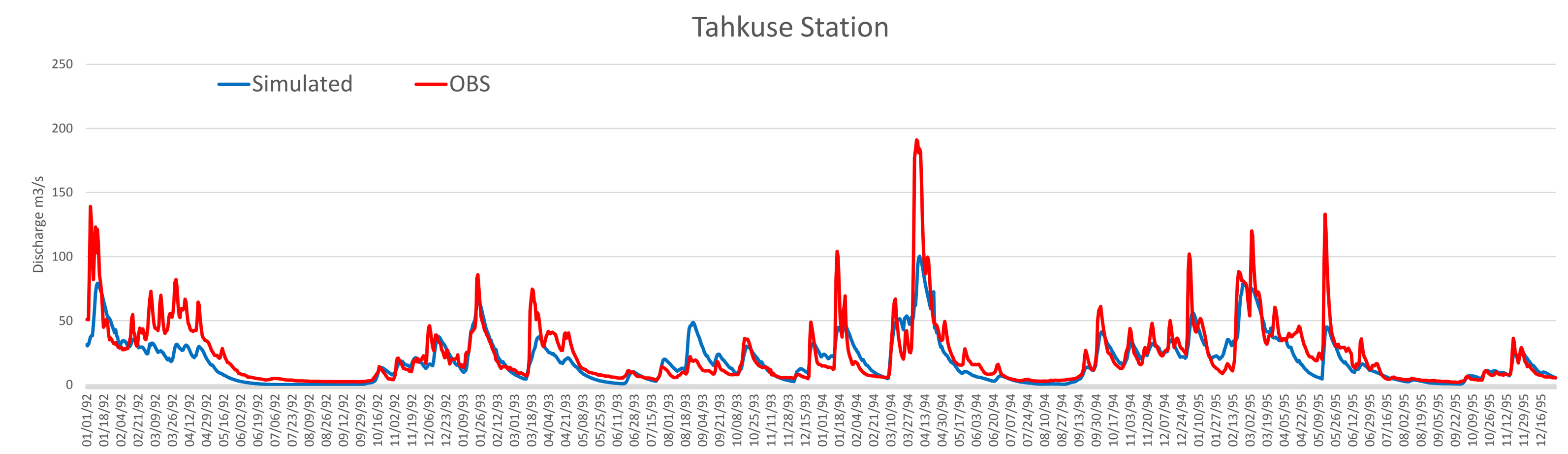
RESULTS

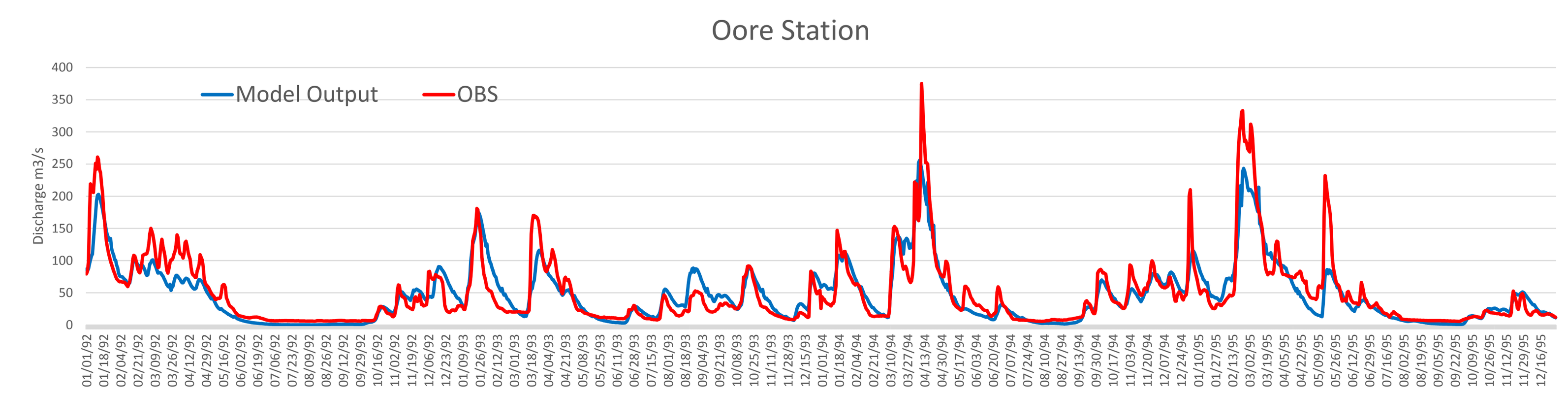
- The model was calibrated for the period of 1992 to 1994 and validated during 1995 for Tahkuse, Riisa and Oore Stations in Pärnu Basin, from 1990 to 1991 was used to warm-up the model. In the case of Emajõgi river, the model was calibrated for the period 2008 to 2011 and validated during 2012 to 2013 for Tartu (Kvissental) station. The period of 2006 to 2007 was used to warm-up the model. The model performance results during the calibration and validation in Pärnu and Emajõgi River are shown in the table.

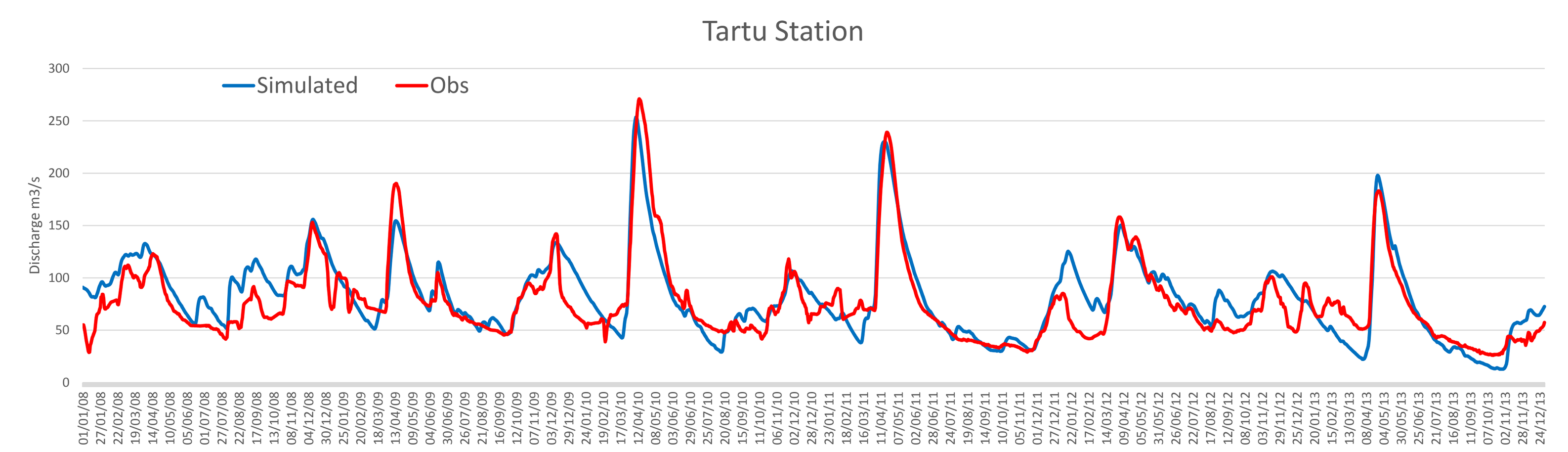
		Model Performance (Calibration Period)		Model Performance (Validation Period)	
Station	River	Nash-Sutcliffe	Regression Coefficient (R2)	Nash-Sutcliffe	Regresion Coefficient (R2)
Riisa	Halliste	0.81	0.82	0.85	0.85
Tahkuse	Pärnu	0.62	0.67	0.71	0.74
Oore	Pärnu	0.79	0.79	0.80	0.86
Tartu (Kvissental)	Suur-Emajógi	0.80	0.76	0.62	0.73

RESULTS









CONCLUSIONS

- During the calibration and validation period the model perform better some stations than others. It is shown by the variations in the results of Nash and R^2 coefficients. All the model evaluation results during the different periods are over the values to be considered acceptable NASH > 0,65 or good NASH >0,75 and (R^2) > 0,5.
- The SWAT model can predict the discharge for the selected hydrometric stations after the calibration and is able to represent satisfactory (silhouette, volume, and peak) of observed flow hydrographs. It is observed some difficulties to predict the peaks in Pärnu River stations. It can be solved by improving the calibration of the model. Also it should be mentioned that the data availability and quality of the inputs can affect the accuracy of the model. In generally the results during the calibration and forecast period can be considered good.
- The model can provide a forecast discharge as many days as long is the range of the weather forecast from the meteorological weather services (HIRLAM or ECMWF)