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INVESTIGATION OF HYDROLOGICAL PROCESSES IN A SMALL CATCHMENT NEAR LAKE BALATON

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Abstract
This study is a part of an ongoing project which aims to integrate knowledge on plot- and catchment scale description of water and mass transport and to evaluate the combined effects of different land use and climate change scenarios on water regime and soil erosion. In this paper we intended to investigate hydrological processes at the scale of their relevance by applying advanced in situ monitoring methods, time series analysis and catchment scale processes in dynamic models. The study was carried out on three reference watersheds around Lake Balaton, Hungary, where plot- and catchment scale parameters were being monitored. The current paper is focusing on presenting the preliminary phase of PERSiST catchment scale model fitting to a selected Somogybabod catchment near Lake Balaton, Hungary.

1. Introduction

Soil and freshwater quality of in any region strongly determine the region's (agro-)ecosystems functioning and the quality of life in that area. Water regime and mass transport through the vadose zone and in surface water courses have major effect on water quality and soil functioning. Erosion damages fertile soils and contributes to the sedimentation and pollution of lakes and rivers, thus, threatening agro- and natural ecosystem. According to predictions, the frequency of extreme weather events will increase in the future (JRC 2009, Pongrácz et al. 2009). Considering the sometimes quite rapid, human induced changes in the landscape, the joint effect of land use and climate changes may lead to so far unknown hydrological situations. Hence, thorough knowledge of factors governing the water and mass transport in soil and water bodies at different scales is needed to understand and manage the functioning of terrestrial and freshwater ecosystems and to develop appropriate tools for mitigating the possible harmful effects of anthropogenic pressures and predicted climate change.
Models have become inevitable tools in risk assessment, planning of measures and scenario analyses regarding effects of land use, agricultural practices and climate change on soil and water quality. One of the basic classifications of the commonly used models concerns their scale validity. Soil scientists commonly apply profile-based models (PBMs) mainly concentrating on water and nutrient regimes in the unsaturated zone. The advanced process-based soil hydrological models use the Richard's equation for calculating water transport in the soil profile and they are appropriate tools for estimating the water and mass balance elements as well as the crop development at plot or field scales. These models, however, cannot consider the effects of different land use and management practices on overall runoff and soil losses from the catchment.
Distributed or semi-distributed watershed-level hydrological models (CBMs), on the other hand, describe transport processes within the catchment, commonly operating with a surface, unsaturated and saturated zone component. These models are usually applied for large catchments, so the reference discharge and water quality data, used for calibration reflect processes, are integrated over large areas. Moreover, the majority of hydrological models (INCA, SWAT etc.) do not incorporate exact, process

based description of transport processes in the unsaturated zone, but use either conceptual or empirical approaches. Consequently, these models can not consider appropriately the effects of actions carried out at plot or field scales.
Our objectives, in particular, are to improve our understanding on the effects of extreme hydrological situation on water regime and soil erosion at field and catchment scales, with special focus on factors and processes that could be altered to increase preparedness and adaptation to foresee land use and climate changes. Furthermore we intend to estimate erosion losses from catchments by applying the process-based INCA-SED dynamic model.

2. Materials and methods

2.1 Pilot areas

The pilot areas for the project implementation are located around the Lake Balaton in S-W Hungary, and they can be considered as representative areas for this region regarding land cover, terrain, soils and water regime. Three small catchments were selected, representing various land use types and sizes ranging between 0,7 to 7 km^2.
In this paper we were focusing on one of the selected study catchments, named Somogybabod catchment (Figure 1.), which is a small sub-catchment of Tetves Creek, which flows into Lake Balaton; hence belonging to south sub-catchment of Lake Balaton. The size of the Somogybabod catchment is 6,8 km^2 and the elevations of the area changing between 105-302 m a.s.l., with relatively steep slopes. In the present study slopes up to 17% were investigated. The annual total precipitation, mean annual evapotranspiration (theoretical) and mean annual temperature of the area are 670 mm, 560 mm and 10.9^{o}C respectively (Tóth, 2004). Soil thickness varies greatly, depending on lithology, geomorphology. Topsoils are mainly brown forest soils with a commonly sandy surface texture. The land use in the catchment area is mostly semi-natural forest and arable land.

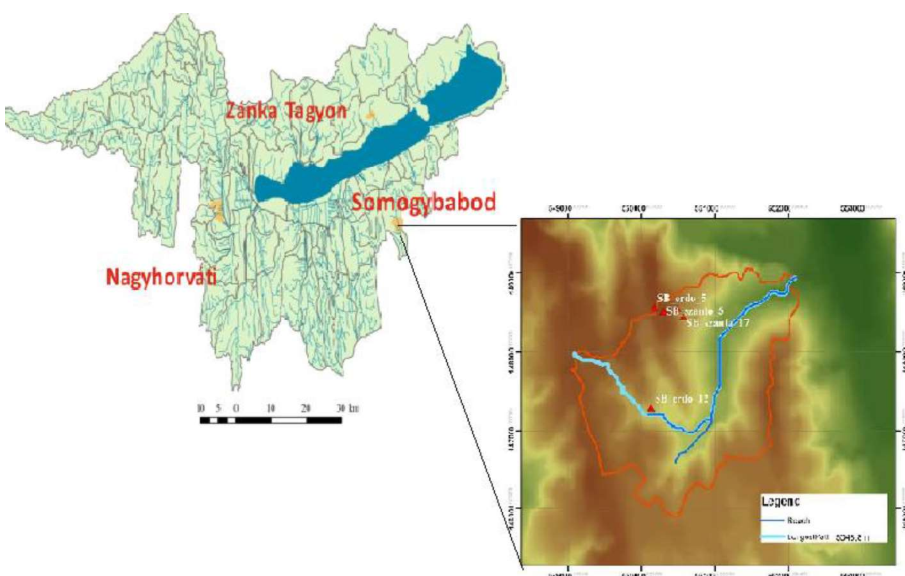

Figure 1. Pilot area

2.2 Model selection

According to the up-to-date statement of the modelling community, hydrological models have to be calibrated at small scales in order to avoid integration of processes over large areas. The optimum catchment size is reported to be below 10 km^2 (Deelstra et al 2010). Therefore, the size of the three small catchments, chosen as pilot areas within the project is optimal for detailed model calibration. The calibrated for each land use type parameter sets will further be validated and tested for the larger – approx. 1500 km^2 – Zala watershed against discharge and water quality data, obtained from Zalaapáti monitoring station.

Preliminary model evaluation has been performed (Farkas and Hagyó, 2010) to select process-based dynamic models that could be used to fulfil the project's objectives. The model selection was based on recently developed benchmark criteria's (Saloranta et al., 2003) considering the rules of "good modelling practice" (van Waveren et al, 1999). Among the catchment-based erosion models the INCA-SED model was selected (Farkas and Hagyó, 2010), because of its profound theoretical background, and moderate data demand (Farkas et al., 2010, Farkas, 2010). The INCA-SED semi-distributed model will be applied for simulating the surface, subsurface runoff and sediment transport from the catchment as well as the discharge and the suspended sediment concentration at the outlet. This model has been successfully applied for several European catchments for describing the water and sediment transport through areas with various land use systems.

The Integrated Catchments (INCA) family of models are widely used for simulating the behavior of nitrogen (Whitehead et al., 1998; Wade et al., 2002), phosphorus (Crossman et al., 2013a, b), sediment (Lazar et al., 2010), dissolved organic carbon (Futter et al., 2007, 2009) and a number of other solutes and pollutants in streams and rivers (Jin et al., 2011; Futter et al., 2012) (Futter et al., 2013). Here we present a rainfall-runoff model, PERSiST (Precipitation, Evapotranspiration and Runoff Simulator for Solute Transport) designed for use with the INCA model family. PERSiST is a semi-distributed bucket-type modelling framework which allows model users to specify a perceptual model of the runoff generation process (Futter et al, 2013).

Runoff generation processes and pathways vary strongly between catchments. Meaningful simulations of solute transport in surface waters are dependent on models which facilitate appropriate, catchment-specific representations of perceptual models of the runoff generation process. PERSiST is a flexible, semi-distributed landscape-scale rainfall-runoff model suitable for simulating a broad range of user-specified perceptual models of runoff generation and stream flow occurring in different climatic regions and landscape types. PERSiST is designed for simulating present-day hydrology; projecting possible future effects of climate or land use change on runoff and catchment water storage. PERSiST generates hydrologic inputs for the Integrated Catchments (INCA) family of models, which relies on external time series of Hydrologically Effective Rainfall (HER; the fraction of precipitation which contributes to runoff) and Soil Moisture Deficits (SMD; the difference between the current depth of water and the waterholding capacity). PERSiST has limited data requirements and is calibrated using observed time series of precipitation, air temperature and runoff (Futter et al., 2015).

2.3 Model description

PERSiST can be a promising tool for using the INCA family of models to assess potential effects of climate and land-management change on surface water quality

PERSiST is a catchment-scale hydrological model recently developed by Martyn Futter (Futter et al., 2013). One of the strengths of the model is that the model simulates runoff at one or more points in a river system. The model operates at a daily time step and is driven by daily series of air temperature and precipitation as well as other catchment characteristics. The model is simple to implement and builds on a series of first-difference equations fully described by Salmonsson (2013).

PERSiST simulates water fluxes from precipitation through the terrestrial part of a catchment and into rivers and streams. Key features include (a) a user-specified model structure suitable for simulating multiple perceptual models of catchment water stores and flow pathways; (b) semi-distributed flow routing incorporating runoff production from multiple hydrologic response types; (c) flow simulations at multiple points in a river network; (d) simple temperature index snowmelt and evapotranspiration routines; (e) abstraction for irrigation and discharge from industrial sources and wastewater treatment sources; (f) catchment and land-cover specific precipitation and snowmelt dynamics; (g) a full water balance; and last but not least (h) generation of input time series files for use with INCA. (Futter et al. 2015).

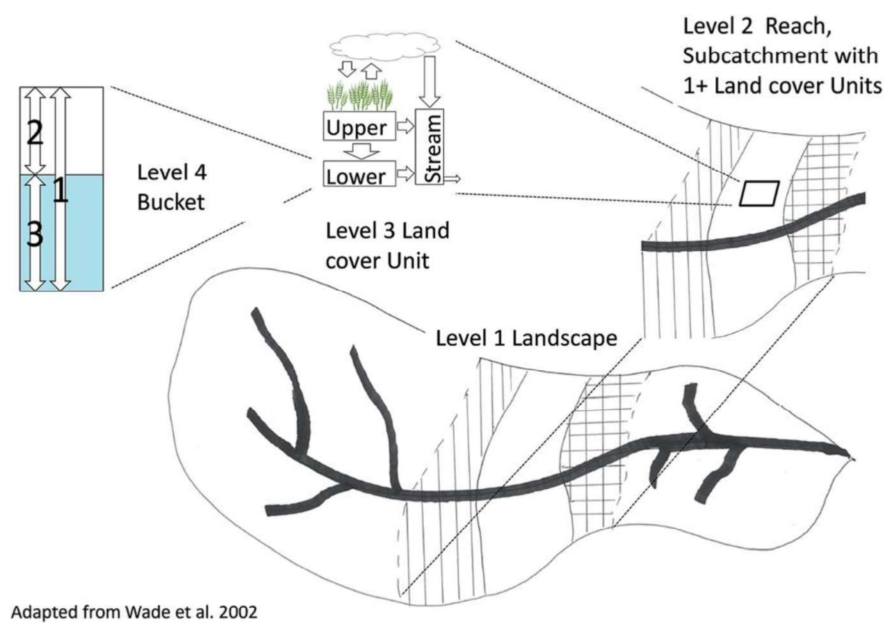

Figure 2. Conceptual representation of the landscape in PERSiST adapted from Wade et al. (2002). A watershed (level 1) is represented as one or more reach/subcatchments (level 2). Within each subcatchment, there are one or more hydrologic response unit (level 3). Each hydrologic response unit is made up of one or more buckets through which water is routed (level 4) (Futter et. al 2013.)

2.4 Model application

For the application presented here, six hydrologic response types were used (Table 1.). Areas of the different hydrologic response types were obtained by generalizing slope condition from application Digital Elevation Model (DEM) and based on CORINE land use categories. The main slope and land use condition were defined in every cells of the 50x50 m grid fitting to Somogybabod catchment.

HYDROLOGIC RESPONSE TYPE	Land use	Arable			Forest		
	Slope	> 5 %	5-17 %	17 % <	> 5 %	5 -17 %	17 % <
COVER PROPORTION (%)		20	23	2	19	25	11

Table 1. Landscape unit

For creating applied dataset, it was crucial to take notice soil hydrophysical properties representative for elevation and land use conditions. Beside spot field sampling and measurement, it was inevitable to create an appropriate soil texture database applying proper estimation.
A single time series of daily average air temperature and precipitation (2005-2014) (Figure 3.) were obtained from Fonyód observation station, which was the drive of the model.

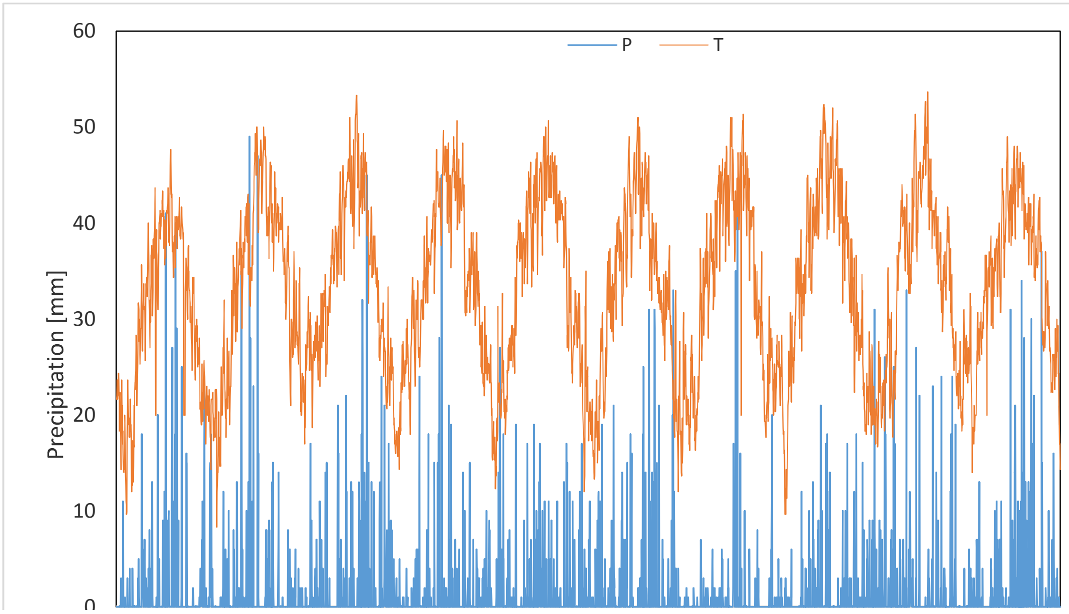

Figure 3. Daily time series of air temperature and precipitation (2005-2014, Fonyód)

Each hydrologic response type was simulated as three vertically stacked buckets representing direct runoff, soil water and groundwater. It was assumed that all precipitation entering the direct runoff bucket percolated to the soil water bucket. Water could leave the soil water bucket as runoff, percolation to groundwater or as saturation excess flow which was routed immediately to the stream. All water entering the groundwater bucket was supposed to flow to the stream. It was assumed that there were no losses to deep groundwater.
The model application was performed for the period 1 January 2005–31 December 2014**.** PERSiST was calibrated against observed stream flows at the outlet of Somogybabod catchment, Visz monitoring station (Figure 4.). The reach length on the study catchment was assessed 9, 8 km.
The model was calibrated by first manually adjusting parameters to improve the fit between modelled and observed stream flow.

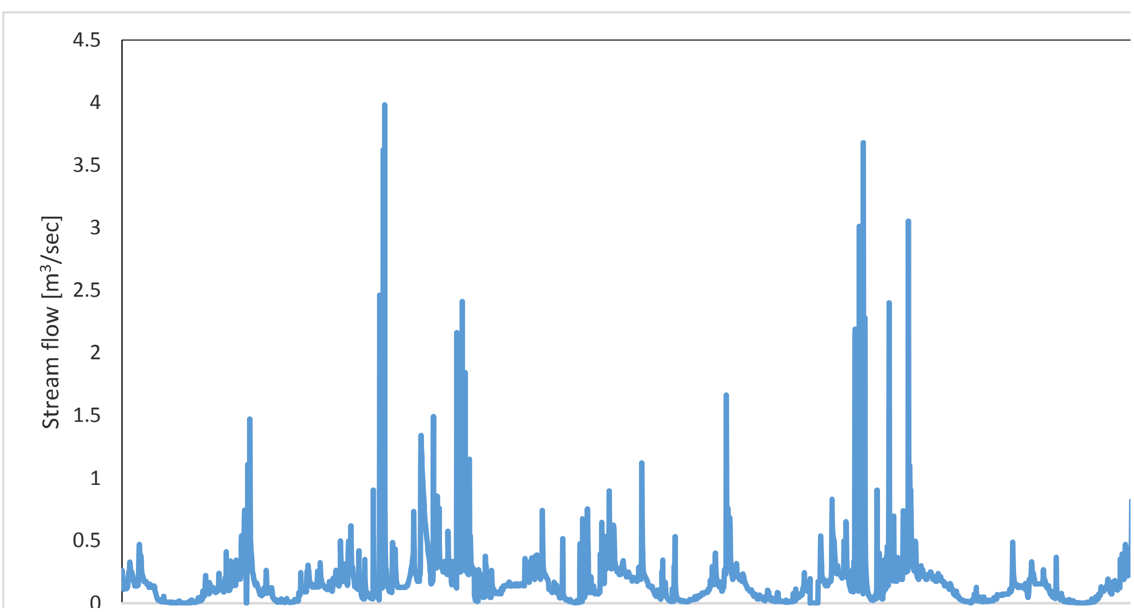

Figure 4. Stream flow (Tetves Creek, Visz, 2003-2014)

3. Results

3.1 Stream flow

Flow simulations based on the complex catchment structures showed that the model was able to reproduce low flow conditions in the creek, but peaks were not fitting exactly. The model was able to reproduce the timing and amount of low flows but tended to miss the timing and amount of peak runoff. In some years, simulated peak runoffs were too low in others. The model was generally able to reproduce the duration of peak flows but tended to produce peaks either too early or too late.

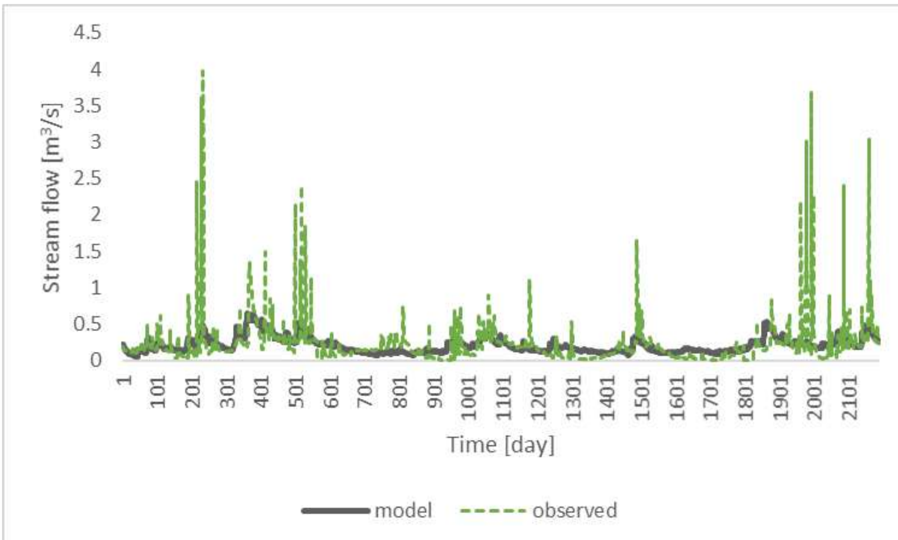

Figure 5. Observed and simulated stream flow

3.2 Runoff generation

Figure 6.-7. show the patterns of simulated runoff in Somogybabod catchment from each hydrologic response type. All of arable covered hydrologic respond types showed notably higher runoff than forest land cover types. While in forest 5-17 % and 17% < type showed very similar runoff amounts until all of three arable land cover type varied broadly and showed greatly higher values.

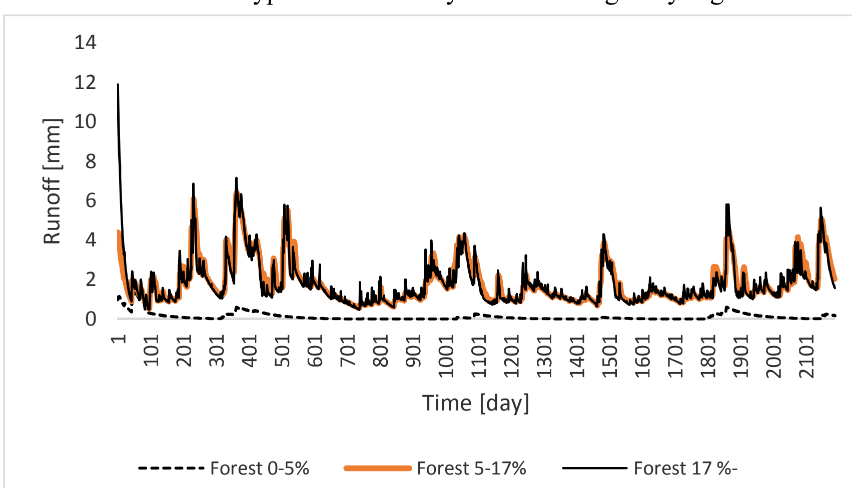

Figure 6. Runoff from forest hydrological respond types simulated by PERSiST

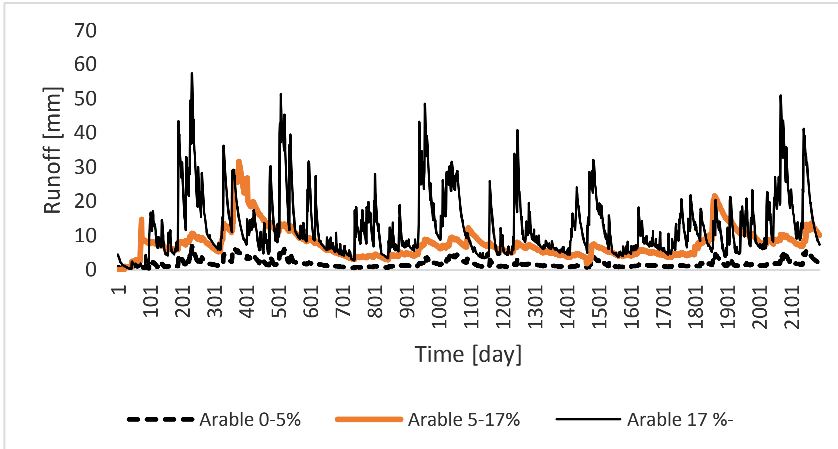

Figure 7. Runoff from arable hydraulic respond types simulated by PERSiST

3.3 Inca input files (SMD and HER)

The seasonal patterns of SMD in Somogybabod catchment (Figure 8.) showed highest soil moisture deficits in the summer and early autumn periods and occurred in arable hydrologic respond types.

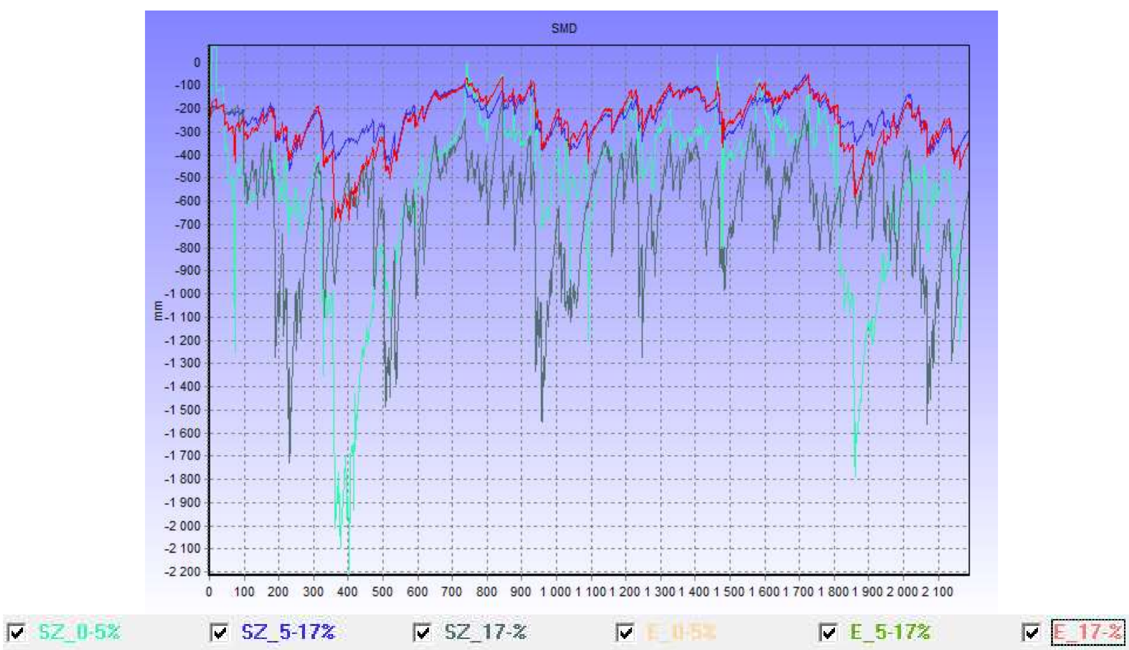

Figure 8. Soil Moisture Deficit (SMD) simulated by PERSiST

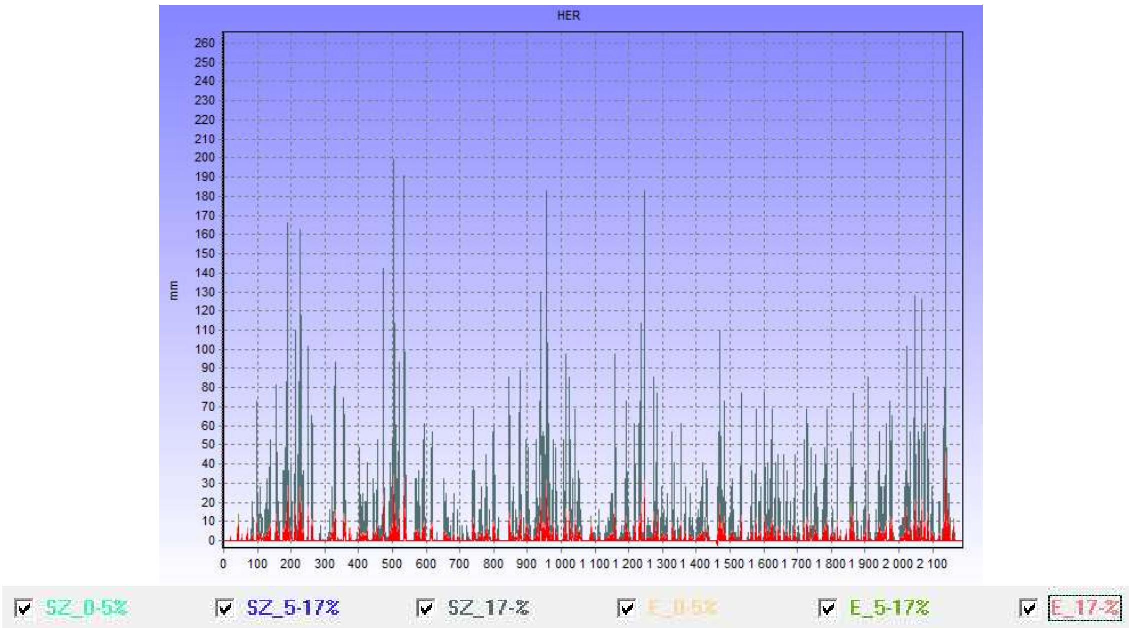

Figure 9. Hydraulically Effective Rainfall (HER) simulated by PERSiST

Hydrologically Effective Rainfall (Figure 9.) occurred with highest values on the arable 17% < and forest 17% < response type mainly in early summer periods.

4. Conclusions

Runoff and streamflow for the years 2005-2015 was simulated using the PERSiST model, calibrated for the Somogybabod catchment. The model was driven by weather data for the study sites from Fonyód observation station. The results show the runoff was notably higher from the arable hydrologic response type than from the forest land cover type.
The streamflow simulation of model needed further calibration. The model was able to reproduce the timing and amount of low flows but tended to miss the timing and amount of peak runoff.
In the future we are planning to apply HBV model, which was developed primarily to usage of INCA. HBV is similarly able to produce INCA-SED input files, as PERSiST, but it has an auto calibration function, which may ease and refine the calibration process and results.

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