CONTINUOUS SIMULATION OF CATCHMENT RUNOFF IN FLOOD FREQUENCY ANALYSIS: A CASE STUDY FROM SLOVAKIA

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1 MOTIVATION

Up till now most of the methods dealing with flood frequency analysis and the estimation of design floods were based on statistical analysis of observed time series of flows. This traditional concept proved to be reliable when estimating design floods with return periods of less than 100 years and in places with long historical records. The trend of increasing safety of new and existing structures together with a slow move from univariate to multivariate flood frequency analysis (FFA) reveal well documented weaknesses of the traditional methods among which, the insufficient length of historical records is the most important one. One of the possible ways how to deal with these new challenges is to artificially lengthen the historical records by synthetic data. In the recent years the science of the world has focused on the development of methods utilizing stochastic weather generators to generate synthetic meteorological and climatic data of arbitrary length and rainfall-runoff models transforming them to synthetic runoff from a catchment.

This study presents a method for continuous flood frequency analysis which utilizes both weather generator and rainfall-runoff model. The method was applied in the Slovak catchment of the River Váh.

2 DATA

The method was applied in the mountainous catchment of the **River Váh** with an **outlet at Liptovský Mikuláš**. The catchment is situated in the northern part of Slovakia between the two highest Slovak mountain ranges, i.e., the High Tatras in the north and the Low Tatras in the south (Fig. 2). It has an **area of 1100.6 km²** with a **mean altitude of 1090.3 m.a.s.l.** and the highest point at 2494 m.a.s.l. The water regime has a strong seasonal effect, with the highest flows in May (Fig. 1) and the lowest in the winter months. **Most of the floods occur in May** and are induced by the rapid melting of snow cover combined with steady rain.

Input data:

- Daily **precipitations** from 28 stations (1981 to 2010); aggregated using IDW interpolation; annual average of **832 mm**.
- Daily **air temperatures** from 6 stations (1981 to 2010); catchment average calculated for mean altitude.
- **Daily** catchment **runoff** (1981 to 2010); annual average of **553 mm**.
- **Hourly** catchment **runoff** (1988 to 2002).

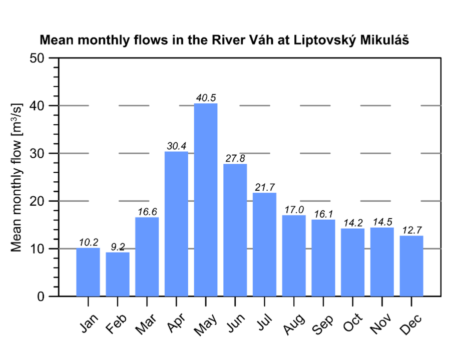


Fig. 1: Mean monthly flows.

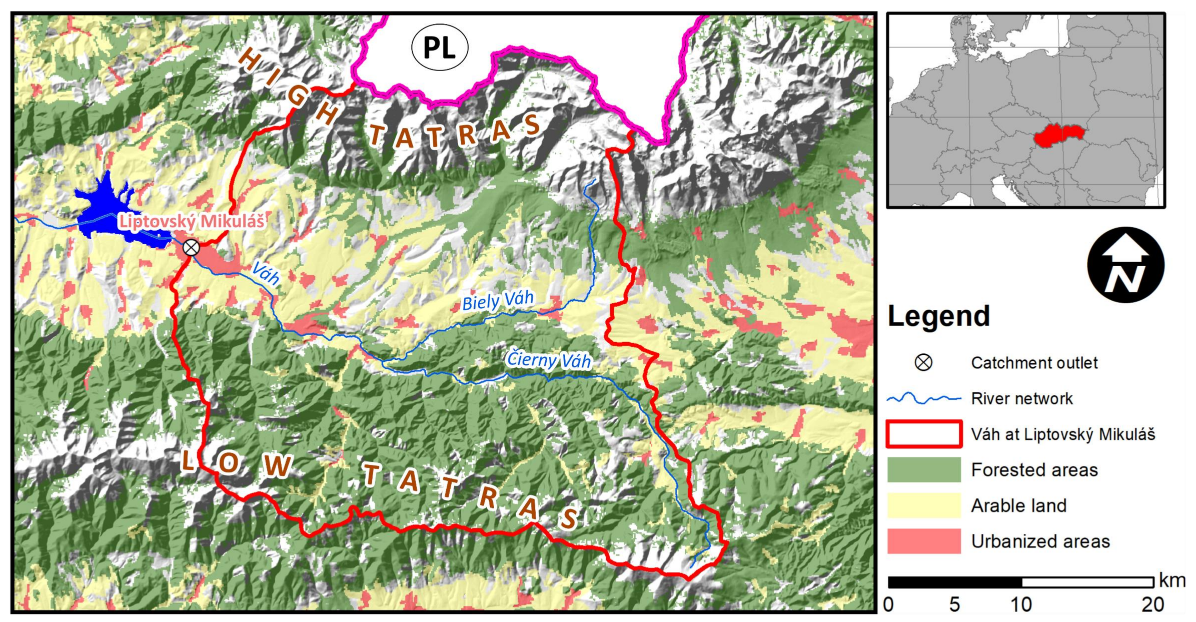


Fig. 2: Position of the watershed of the River Váh in Slovakia.

3 METHODOLOGY

The presented method belongs to the group **of FFA techniques utilizing continuous simulation of catchment runoff**. It utilizes a **stochastic weather generator WGbRV** (Výleta, 2013) to generate 10,000 years of daily precipitation amounts and air temperatures and **a rainfall-runoff model KZOM** (Valent, 2014) used for their transformation into a time series of equally long synthetic flows.

Weather generator

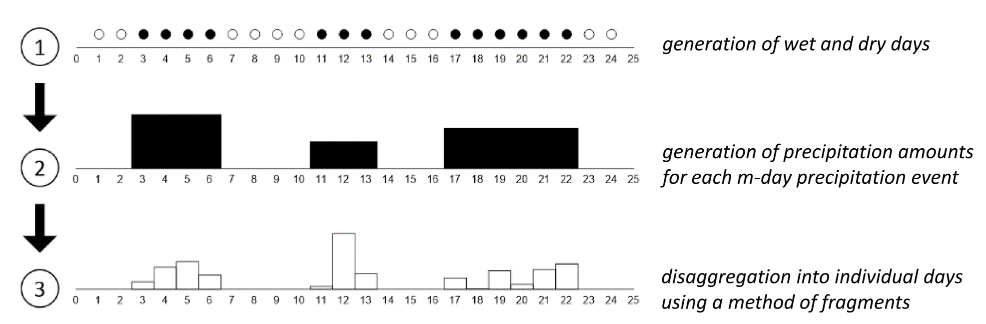
Precipitation model

Occurrence model

- generates a time series with an information whether the day was wet or dry
- utilizes a Markov model of order 1 to 3
- optimizes the order of the model for each calendar moth using a harmonic search algorithm

Amount model

- generates precipitation amount for a selected m-day precipitation event using a statistical distribution
- various statistical distributions for all combinations of calendar months and m-day precipitation events
- disaggregation of precipitation events into individual days using a method of fragments (Svanidze, 1980)



Air temperature model

- takes into account the seasonality and the precipitation occurrence
- utilizes statistical analysis and smoothing using a harmonic function and an autoregressive model of first order

R-R model

- R-R model KZOM - deterministic conceptual lumped model
- 14 free parameters
- harmony search algorithm used for optimization
- **2 regimes** for separate simulation of low and high flows ⟶ 2 sets of model parameters
- **1. set** (low flows) calibrated on the whole dataset using Nash-Sutcliffe criterion (NS)
- **2. set** (high flows) calibrated on annual maximum flows ±2 days using the optimization function minimizing NS of time and rank ordered flows (Paquet et al., 2013)
- the threshold between low and high flows was calibrated using a genetic algorithm
- the decision which regime is used to simulate flow in day *i* depends on the value of the flow in the previous day *i*-1

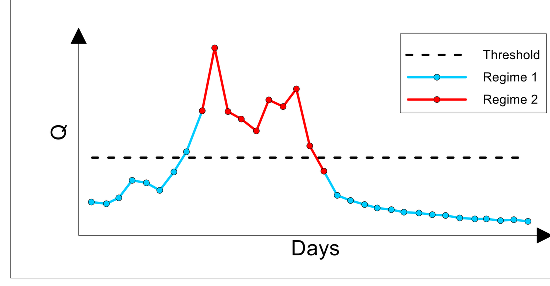
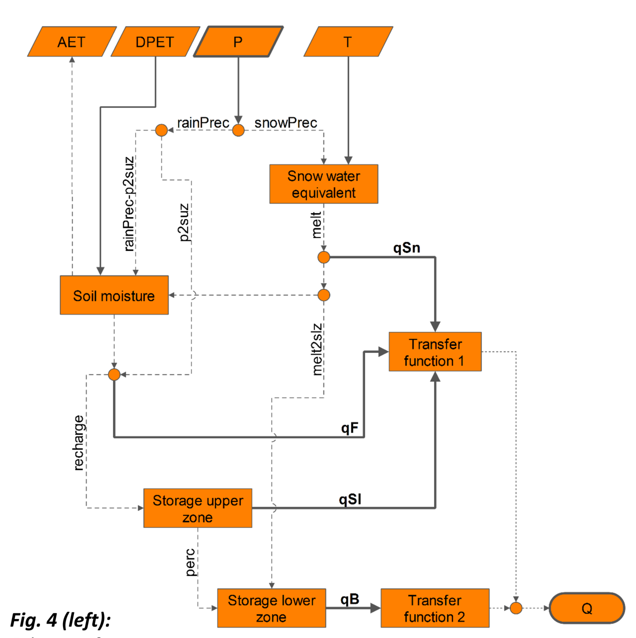


Fig. 4 (left): *Scheme of assigning flows to one of the two regimes. Based on the flow value in the previous day relative to the threshold.*



P - precipitation,
T - temperature,
DPET - daily potential evapotranspiration,
AET - actual evapotranspiration,
qSn - runoff induced by fast melting of snow cover,
qF - fast runoff (overland and hypodermic flow),
qSl - slow runoff (hypodermic flow),
qB - base flow.

Flood frequency analysis

1. **Data analysis**
   - analysis of precipitation and air temperature input time series
2. **Weather generator**
   - generation of 10,000 years of synthetic daily time series of precipitations and air temperatures
3. **R-R model calibration**
   - model calibration on measured flows
4. **Runoff simulation**
   - transformation of synthetic inputs into flows
5. **Traditional FFA**
   - traditional FFA of synthetic flows
   - N-year floods estimated directly from empirical cumulative distribution functions
6. **Q24h to Q1h**
   - both WG and R-R model work in a daily time step
   - transformation between daily and hourly flows (flood peak)
   - transformation based on the analysis of selected flood hydrographs (in hourly time step)

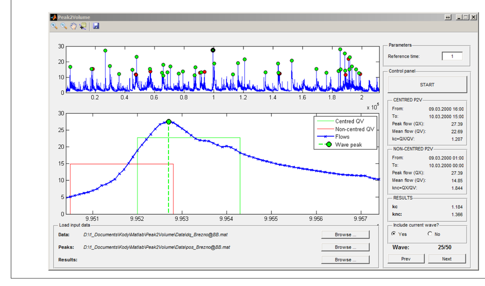


Fig. 5: *Analysis of the relation between peak (Q_{1h}) and average daily flow (Q_{24h}) in a GUI developed in the Matlab environment.*

4 RESULTS

Weather generator

- **generated 10,000 years** of daily air temperatures and precipitations
- the comparison of selected statistical characteristics of observed and synthetic data showed that the generator gives good results in describing both mean and extreme precipitations
- the model also generated precipitations that were higher than the maximum precipitation in the historical record

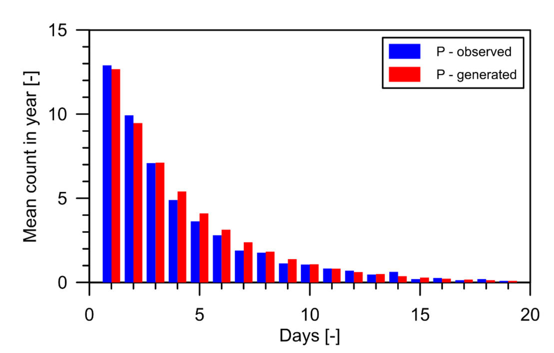


Fig. 6:
Comparison of the mean number of wet periods of particular length in a year in observed and synthetic time series.

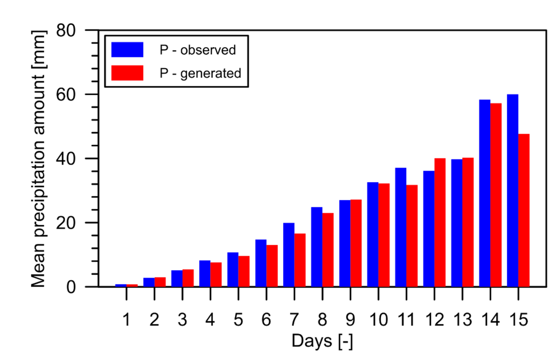


Fig. 7:
Comparison of mean m-day precipitations of particular duration in observed and synthetic time series.

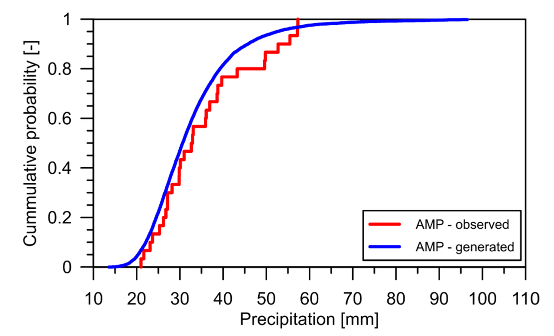


Fig. 8:
Comparison of empirical cumulative distribution function of annual maximum precipitations.

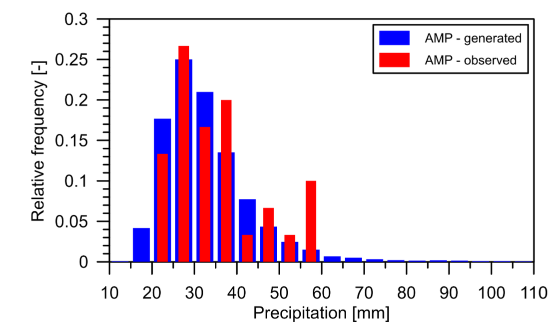


Fig. 9:
Comparison of histogram of annual maximum precipitations.

R-R modelling

- model calibration on the whole period (1981 to 2010)
- **separate simulation of low and high flows** ⟶ significant improvement of the simulation of extreme flows
- Nash-Sutcliffe = 0.70
- visual assessment showed a good fit between observed and simulated flows
- **weak simulation of extreme flows** – semi-distributed approach would be more appropriate (not possible as a single-site WG was used)

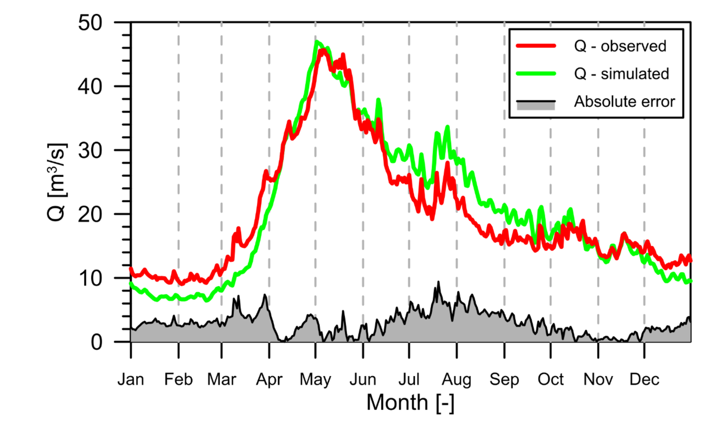


Fig. 10:
Comparison of interannual flow regimes calculated for observed and simulated.

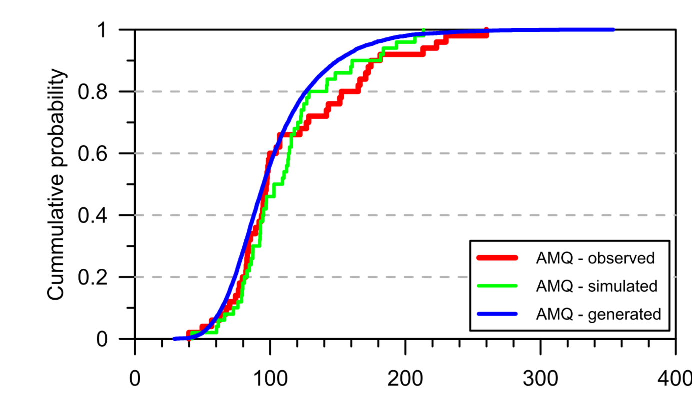


Fig. 11:
Comparison of empirical cumulative distribution function calculated for observed, simulated and generated (synthetic) annual maximum flows.

5 CONCLUSIONS

- The stochastic weather generator proved to be robust enough to satisfactorily simulate observed precipitation and air temperature time series.
- It preserved most of the statistical characteristics of the observed time series and enables to generate even values, which were not present in the historical record.
- The generated AM series of precipitations comprised fewer values in a range between 55 and 60 mm than the one observed (Fig. 9).
- In the R-R modelling a separate simulation of low and high flows was introduced. This led to a significant improvement of the simulation of extreme flows while preserving a good simulation of low and medium flows.
- However, the model did not performed very well when simulating the most extreme floods.
- The great steepness of the hypsometric curve called for a semi-distributed modelling approach, in which the model inputs would be divided into several elevation zones.

6 ACKNOWLEDGEMENTS

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References:

Paquet, E., Garavaglia, F., Garçon, R., Gailhard, J. (2013): „The SCHADEX method: A semi-continuous rainfall-runoff simulation for extreme flood estimation“, *Journal of Hydrology*, 495, p. 23-37.

Svanidze, G.G. (1980): *Mathematical Modeling of Hydrologic Series*, Water Resources Publications, USA.

Valent, P. (2014): *Rainfall-runoff modelling for flood frequency* analysis (dissertation thesis), Slovak University of Technology in Bratislava (in Slovak).

Výleta, R. (2013): *Modelling areal precipitation amounts for flood frequency analysis* (dissertation thesis), Slovak University of Technology in Bratislava (in Slovak).