Importance of temporal and spatial resolution in modelling hydrological extremes in a small catchment

Case study of conceptual HBV model application in the Rietholzbach catchment, Switzerland

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1. Experimental site of Rietholzbach catchment, Switzerland

Fig. 1: Location of the experimental site of Rietholzbach catchment in northern Switzerland

Small hilly pre-alpine catchment of the Rietholzbach stream (3,2 km²) lies in the middle part of the Thur basin (tributary to Rhine). Altitude ranges from 680 to 950 m a.s.l., mainly north- and south facing slopes are of average slope 29%. Experimental site has been operated since 1976, currently by Institute for Atmospheric and Climate Science of ETH Zurich

Climatic parameters (1976-2007):

Annual precipitation: 1465 mm
Mean daily discharge: 108 l/s
Mean annual temperature: 7° C

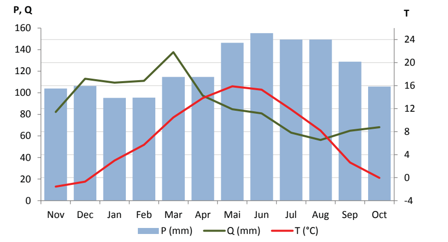


Fig. 2: Monthly precipitation, runoff and tepmerature averages over period 1976 - 2007

Land use:

73% pastures, grassland
24% forest (mainly coniferous)
2% settlements & roads
1% wetlands

Soils: Cambisol, Regosol, Gley soil

Measured variables:

3x discharge, precipitation incl. snowfall, air and water temperature, actual evapotranspiration and large variety of others. For details see:

http://www.iac.ethz.ch/groups/seneviratne/research/rietholzbach

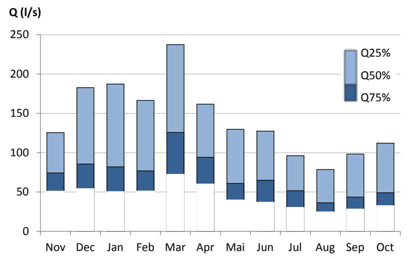


Fig. 3: Daily runoff quantiles

Fig. 4: Extreme runoff characteristics obtained with frequency analysis

Daily mean quantiles			Maximum daily discharges			N-years return period peaks		
Q_{90d}	121.1	l/s	Q_{a5}	1.69	m³/s	Q_5	4.48	m³/s
Q_{180d}	55.2	l/s	Q_{a10}	1.96	m³/s	Q_{10}	5.42	m³/s
Q_{270d}	28.9	l/s	Q_{a20}	2.23	m³/s	Q_{20}	6.35	m³/s
Q_{355d}	11.0	l/s	Q_{a50}	2.56	m³/s	Q_{50}	7.58	m³/s
15-days minimum	12.0	l/s	Q_{a100}	2.82	m³/s	Q_{100}	8.54	m³/s

2. HBV light - model and data used for the study

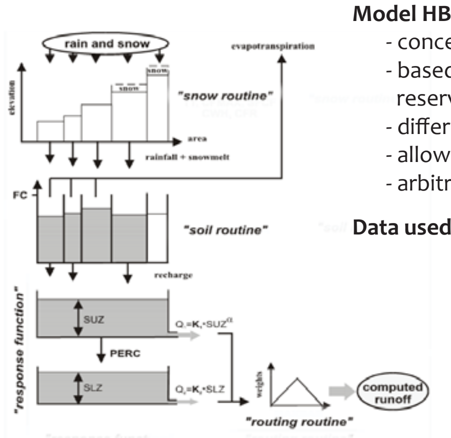


Fig. 5: "Standard" model structure of the HBV

Model HBV-light:

- conceptual semi-distributed hydrological model
- based on the concept of several connected linear reservoirs with variable response velocity
- different model structures = spatial variability of inputs
- allow separate subcatchments
- arbitrary computational time step

Data used for the simulations (mainly for 1976-2007):

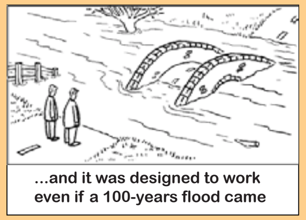
Temperature: hourly, daily derived
Discharge: hourly (outlet), daily derived
hourly 2005-2007 (subcatchment)
Precipitation: hourly, daily derived
Evapotransp.:
Monthly totals distributed into days according to daily temperature, into hourly step by an empirical sinusoidal function

MAIN QUESTIONS OF THE STUDY

A. Does the use of long-term hydrological simulations guarantee sufficient accuracy for extreme flows estimation, even using a well calibrated model?

B. What is the role of temporal resolution in modelling hydrological extremes in a small catchment?

C. Is there a way of improving model reliability in adding more spatial information and how much into detail do we need to go?



RESULTS AND OBSERVATIONS

❶ Different model structures and variations with several elevation zones and/or aspect of the slopes proved to have negligible effect on the overall of fit as well as on accuracy of extreme flow characteristics.

❷ Too lax limits for slow response coefficient automatic calibration are very unappropriate. Reasonable limits must be determined with the depletion curves analysis.

❸ Even a good fit of daily step model didn't ensure reliable estimates of extreme flows.

Discharge characteristic		Q_{90d}	Q_{180d}	Q_{270d}	Q_{355d}	Q_{15days} min	Q_{a5}	Q_{a10}	Q_{a20}	Q_{a50}	Q_{a100}	Q_5	Q_{10}	Q_{20}	Q_{50}	Q_{100}
Daily sim	**NSE**	106%	113%	105%	166%	158%	88%	86%	83%	82%	80%	---	---	---	---	---
	NSE log	99%	118%	112%	145%	138%	70%	68%	65%	63%	61%	---	---	---	---	---
Hourly sim	**NSE**	100%	126%	133%	86%	80%	109%	109%	108%	107%	106%	72%	68%	66%	63%	61%
	NSE log	92%	119%	143%	138%	126%	105%	104%	102%	101%	100%	58%	55%	52%	49%	47%

Fig. 7: Comparison of daily and hourly models' ability to reproduce extreme discharge characteristics expressed as a percentage of observed values. Results are given for two objective functions used for calibration of the HBV-light model.

❹ Worse overall fit was observed for the hourly model, even after aggregating outputs to daily values. In the same time considerable increase of accuracy for extreme discharges was discovered. Absolute peak flows were systematically underestimated, ranging from 61 to 72%

❺ Adding one subcatchment into hourly model increased its fit to the level of lumped daily model. Already good enough estimates of maximum daily flows were reproduced even better and low flow characteristics were equally accurate. The variability of absolute flood peaks decreased to the range of 1%, althoug being still underestimated. However fit for the discharge from the subcatchment was rather poor and such model can't be used in any case for estimating flows in the subcatchment.

Q_{90d}	Q_{180d}	Q_{270d}	Q_{355d}	Q_{15days} min
112%	147%	158%	105%	100%
Q_{a5}	**Q_{a10}**	**Q_{a20}**	**Q_{a50}**	**Q_{a100}**
101%	103%	103%	104%	105%
Q_5	**Q_{10}**	**Q_{20}**	**Q_{50}**	**Q_{100}**
70%	70%	71%	71%	71%

Fig. 8: Accuracy of extreme discharge characteristics of the 2 subcatchment model

❻ Adding third subcatchment led to overall dicrease in model accuracy. It is unadvisable doing so unless it's possible to calibrate the model also with respect to the subcatchment data.

Q_{90d}	Q_{180d}	Q_{270d}	Q_{355d}	Q_{15days} min
110%	145%	170%	154%	145%
Q_{a5}	**Q_{a10}**	**Q_{a20}**	**Q_{a50}**	**Q_{a100}**
85%	86%	86%	86%	86%
Q_5	**Q_{10}**	**Q_{20}**	**Q_{50}**	**Q_{100}**
57%	55%	53%	52%	50%

Fig. 9: Accuracy of extreme discharge characteristics of the 3 subcatchment model

3. Temporal resolution - comparison of daily and hourly step results

In order to compare daily and hourly model behaviour hourly simulation was carried out with two years of calibration period and several validation periods. Results for the whole 30-years period were then aggregated into the daily values and compared with the observed data.
Goodness of fit was evaluated both for the hourly as well as aggregated monthly simulation and the characteristics of the extreme discharges were determined with the frequency analysis.

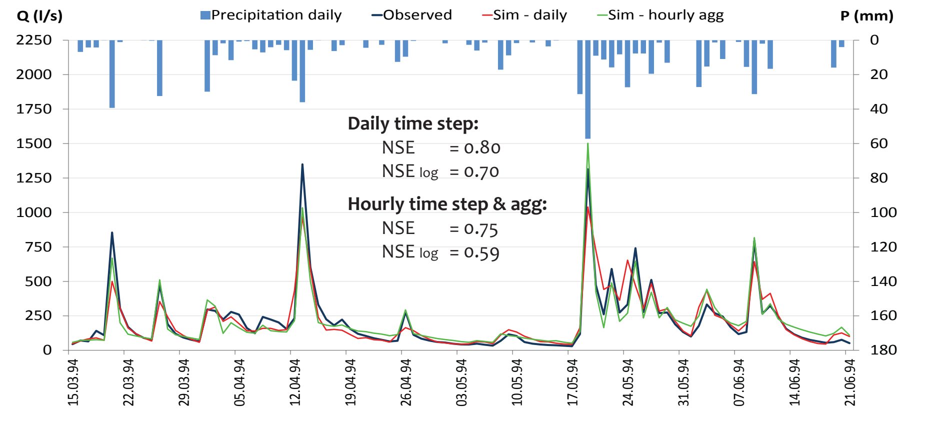


Fig. 6: Example of simulated period with worse fit of daily model but more reliable in reproducing extreme flows

Despite the very good fit of the hourly model for particular calibration periods (up to 0.91), overall fit for the whole simulation period was always worse than in the daily model. This is probably caused by more "noise" contained in the hourly data. Slightly worse was also fit to the daily observations after aggregation. However aggregated hourly data proved to be much more flexible and reproduced more consistent and surprisingly accurate estimates of the extreme discharges.

4. Spatial resolution - lumped or semidistributed?

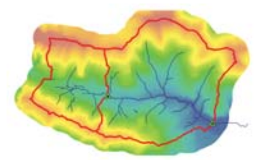
Besides the influence of the temporal resolution also adding a spatial information into the model was tested. Watershed was devided into two and subsequently into three subcatchments. Model was calibrated to the lowest outlet discharge using two years of hourly data and verified on the subcatchment data. Overall fit for the whole 30 years period was evaluated and frequency analysis carried out.

Subcatchment information:

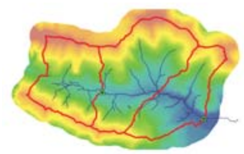
Data period: 2005-2007
Area: 0,9 km² (28% of total area)

Best fit for subcatchment only, calibrated for:

NSE: NSE = 0,59 NSE log = 0,58
NSE log: NSE = 0,53 NSE log = 0,78



2 subcatchments model: **NSE / NSElog**
Fit for calibration period: 0,75 / 0,69
Overall fit (hourly step): 0,76 / 0,73
Overall fit (agg. into dayly): 0,80
Validation on subcatchment: **0,45 / 0,01**



3 subcatchments model: **NSE / NSElog**
Fit for calibration period: 0,74 / 0,65
Overall fit (hourly step): 0,76 / 0,67
Overall fit (agg. into dayly): 0,79
Validation on subcatchment: **0,37 / -1,25**

Acknowledgments

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