Semi-automatic calibration of the LARSIM model using the SCE-UA method in respect of high-flow simulation

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1. Motivation

- Inadequate flood forecasting model
  Current LARSIM model from the Bavarian Environment Agency (LfU) can be improved for the use of flood forecast at the Upper Main Catchment, Germany. → Recalibration is suggested.

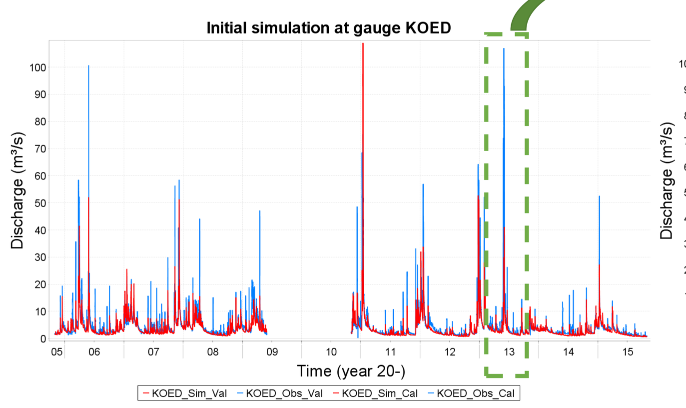

Figure 1: Initial simulation applying model from LfU at gauge Ködnitz

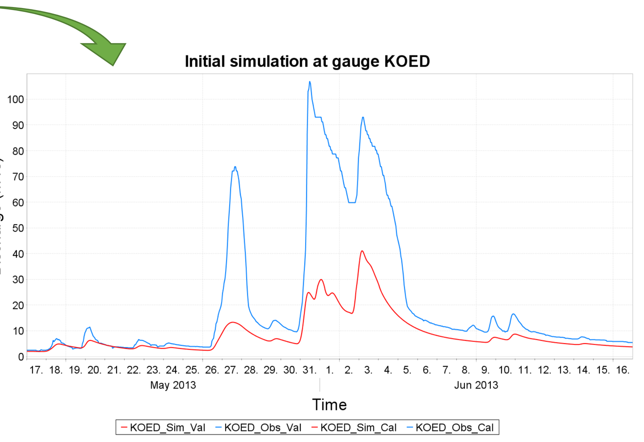

Figure 2: Initial simulation applying model from LfU at gauge Ködnitz (highly underestimates the largest flow event)

- Issue of parameter equifinality
  Different sets of parameter values can produce very similar objective function results, which are worth considering as the acceptable parameter sets for simulation[1]. → Does the global optimum parameter set on the response surface always perform better than the local optima sets?

2. Objectives

- Examine the phenomenon of parameter equifinality through a series of simulated flows by different parameter configurations returned by each evolutionary loop from the modified SCE-UA algorithm.
- Purpose a semi-automatic calibration method to determine parameters that are able to generate the best fit to the observed discharge in the high flow domain.

3. Study Area & Data

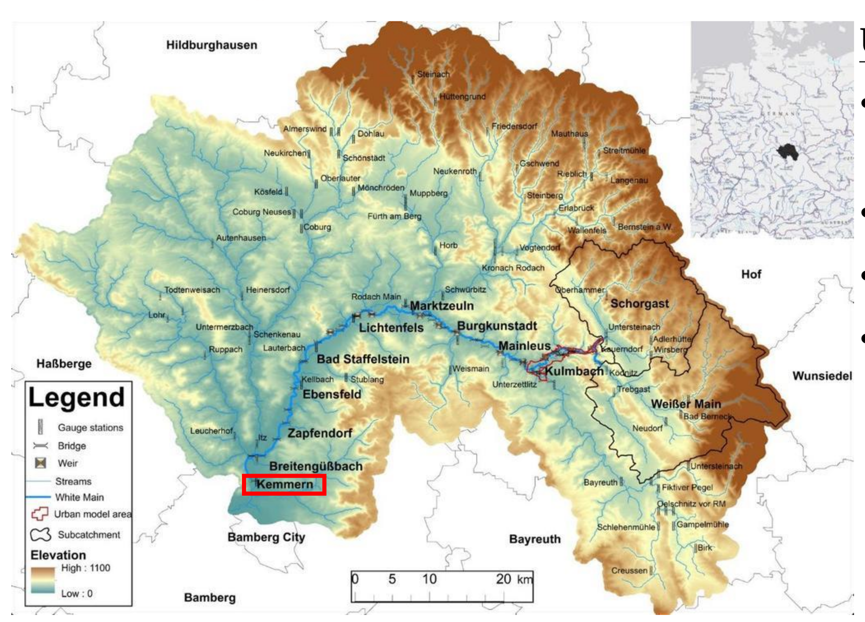

Figure 3: The Upper Main Catchment and gauges within the river basin (gauge Kemmern marked in red: closest gauge to the basin outlet)

Upper Main Catchment

- North-East of the national state Bavaria in Germany
- Area: 4646 km²
- 50 gauging stations
- Observed hourly discharge at multiple gages as well as the meteorological data are applied between 2010 and 2015 for calibration and between 2005 and 2009 for validation.

4. LARSIM model

- LARSIM stands for "Large Area Runoff Simulation Model".
- 34 model parameters and 6 types of meteorological data are model inputs to simulate the hydrological responses.

Table 1: Model classification of LARSIM

LARSIM model classification	
Process description	Conceptual model
Spatial presentation	Distributed (large subareas)
Aspect of randomness	Deterministic model

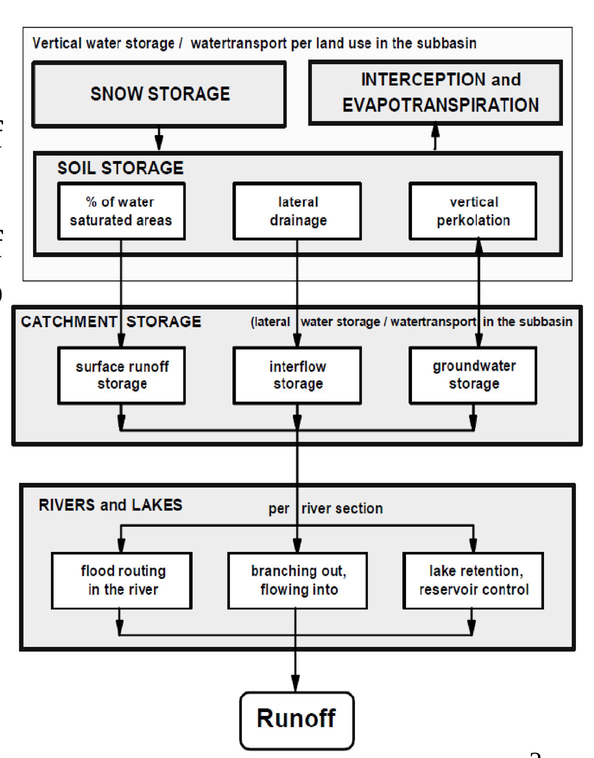

Figure 4: Model scheme of LARSIM[2]

5. Shuffled Complex Evolution Algorithm[3]

- Based on the notion of "Information sharing" and "Biological evolution"
- Efficient to find the global optimum parameter set on the response surface

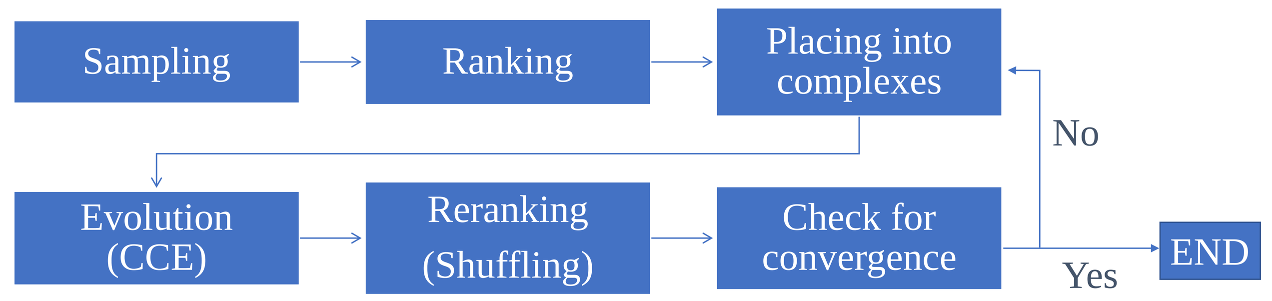

Figure 5: Flowchart of the SCE-UA algorithm

- Competitive Complex Evolution (CCE)

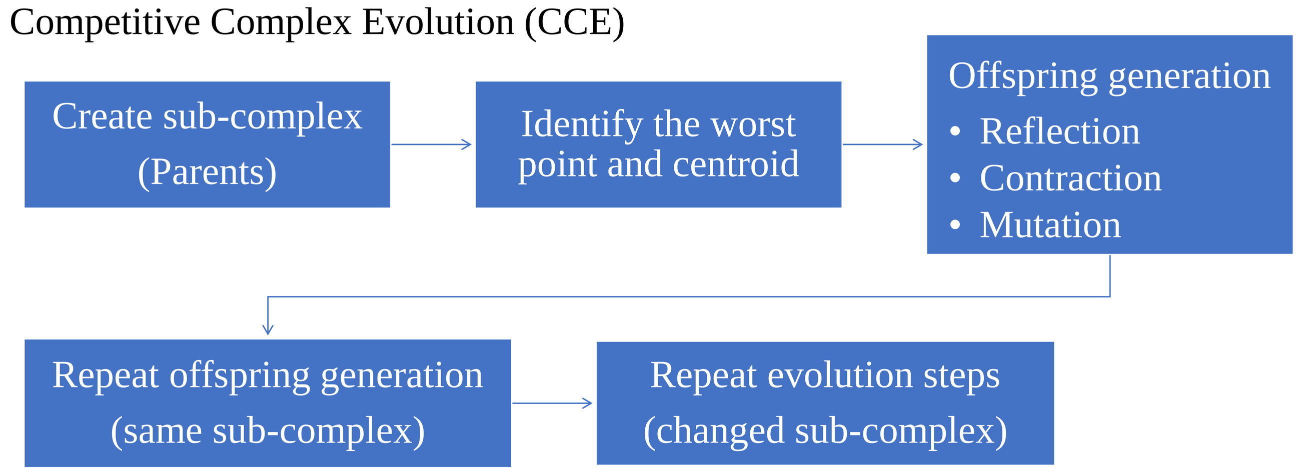

Figure 6: Flowchart of the Competitive Complex Evolution process

6. Research Process

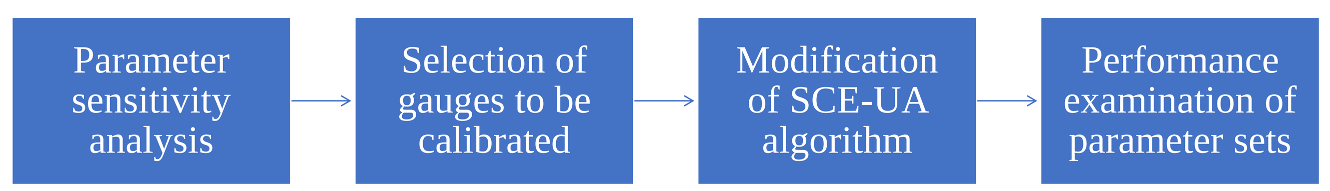

Figure 7: Flowchart of the research procedure

6.1 Parameter sensitivity analysis

- A sensitivity analysis determines 10 parameters in the LARSIM model having the greatest influences on the simulation in the high flow domain, listed in table 2.

Table 2: 10 parameters in LARSIM model selected to be calibrated

Parameter	Description
EQD	Retaining constant of the slow runoff storage
EQD2	Retaining constant of the fast runoff storage
A2	Threshold value of the fast and slow direct runoff
BSF	Exponent of the soil moisture saturation area function for adjustment of the share of runoff as a function of the soil storage load
beta	Drainage index for the deep seepage
Dmax	Index for lateral drainage to the interflow storage in the area of large grain sizes
KG	Correction factor for the areal precipitation
TGr	Mean temperature of the transition zone from snowfall to rain
WZBo	Threshold value of the water content of middle soil storage
SRet	Coefficient for the retention of liquid water in the snow pack

6.2 Selection of gauges to be calibrated

- Criteria: Contributing area ≥ 100 km² and Original NSE value from LfU ≤ 0.8
- 14 gauges are selected to be calibrated: Wirsberg, Bad Berneck (Weißer Main and Ölschnitz), Trebgast, Autenhausen, Coburg, Unterzettlitz, Lohr, Kauerndorf, Ködnitz, Heinersdorf, Leucherhof, Schenkenau and Kemmern

6.3 Modification of SCE-UA algorithm

- The CCE sub-algorithm is modified to fulfill the physical meaning of the 4 discharge storage components (baseflow, interflow, slow and fast surface runoff). An increase of the retention constant causes a flatter wave rise and drop and thus a lower peak. Hence, the criterion should be set as EQB > EQI > EQD > EQD2.
- The SCE-UA algorithm is modified to return the parameter set with the highest NSE value after each evolutionary loop, including the local optima and global optimum set on the response surface, allowing us to examine their performance in the following step.

6.4 Performance examination of parameter sets

- Weighted absolute error in the high flow domain (above mean high flow MHQ)

$$w_i = \frac{Q_{i\_obs}}{\sum Q_{\_obs}}$$

$$Weighted\ absolute\ error = \sum \left[\left| \left(Q_{i_{obs}} - Q_{i\_sim} \right) \right| \times w_i \right]$$

wi (-) represents the weighting factor for the event i; Qi_obs (m³/s) represents the observed discharge of event i; Q_obs (m³/s) represents the set of observed discharges above MHQ; Qi_sim (m³/s) represents the simulated discharge for event i

- Weighted NSE value for the calibration and validation period

$$NSE_{weighted} = \left(NSE_{Cal} \times \frac{t_{cal}}{t_{cal} + t_{val}} \right) + \left(NSE_{Val} \times \frac{t_{val}}{t_{cal} + t_{val}} \right)$$

$NSEweighted$ (-) represents the weighted NSE value for the calibration and validation period; $NSECal$ (-) and $NSEVal$ (-) represents the NSE value for the calibration and validation period respectively; $tcal$ (hr) and $tval$ (hr) is the timespan for calibration and validation respectively

- Plausibility of the hydrograph components
  The plausibility check of the baseflow, interflow and high flow is conducted in order to confirm the most representative parameter set. The criteria for each flow regime are described as the following[4].
  - **Baseflow** has a "long-term" memory and provides information of the variations between wet and dry years. An increased baseflow in spring seasons reflects the seasonal cycle due to snowmelt events.
  - **Interflow** is significantly involved in the runoff during wet seasons when the discharge increases over several days to weeks. Together with baseflow, interflow provides information at the recession limb of flow events.
  - **High flow** simulations determine the flood prediction capacity of the model, which is the focal point in this study. A reliable high flow simulation provides a good fit to the rising limb of flow (time and gradient) and the flow peak (time and peak value).

7. Results

Example of gauge Heinersdorf: 4 considered parameter sets (PS)

(PS3: global optimum; PS1 and PS2: local optima; PS0: initial set from LfU)

- Weighted absolute error in the high flow domain ranking: PS3 > PS2 > PS1 > PS0
- Weighted NSE value for the entire period ranking: PS2 > PS1 > PS3 > PS0
- Plausibility of the hydrograph components

Baseflow & Interflow simulation

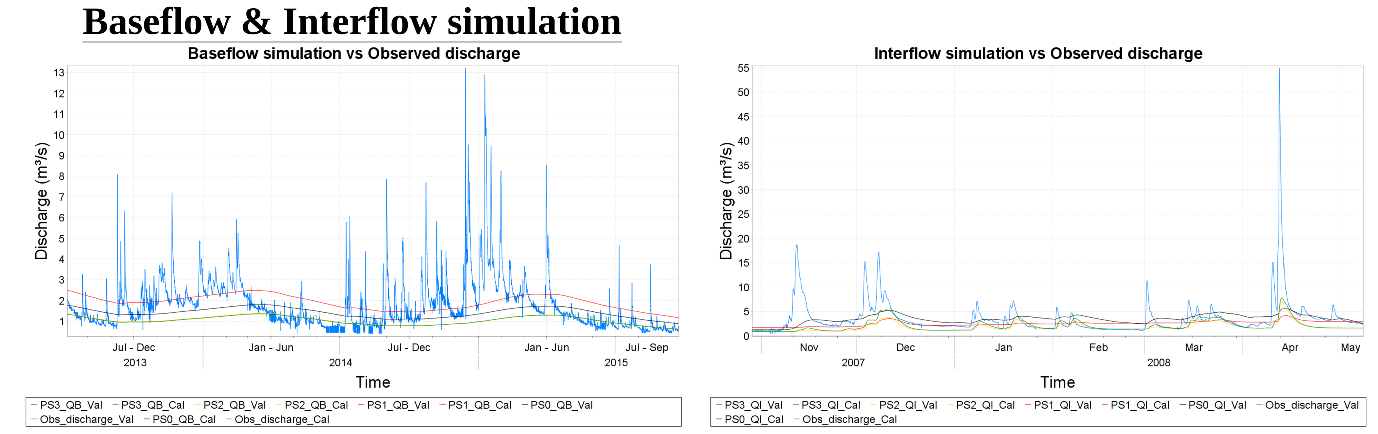

Figure 8: Baseflow and Interflow simulation at gauge Heinersdorf

High flow simulation

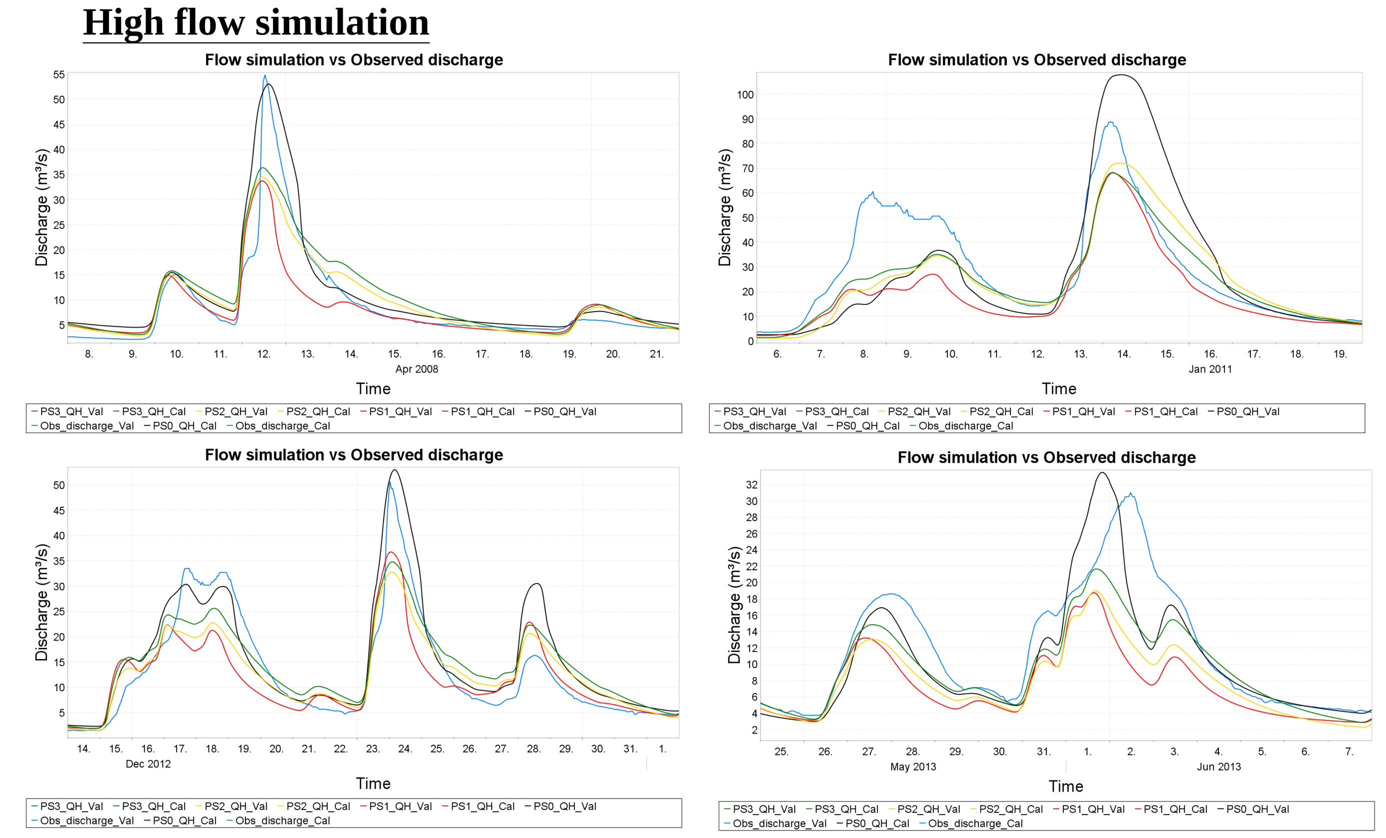

Figure 9: Simulations during 4 largest flow events at gauge Heinersdorf (PS0 outranges other sets)

8. Discussion

- **Issue of parameter equifinality**
  According to the result, the global optimum parameter set does not necessarily return the best simulations and it only becomes representative at 5 of the 14 calibrated gauges. Whereas at other gauges, either the initial or one of the local optima sets performs better than the global optimum set.
- **Effectiveness of the semi-automatic calibration (Before / After calibration)**

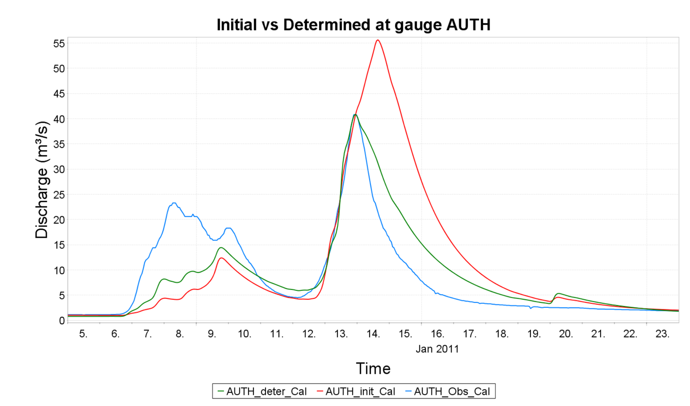

Figure 10: Flow simulation at gauge Autenhausen

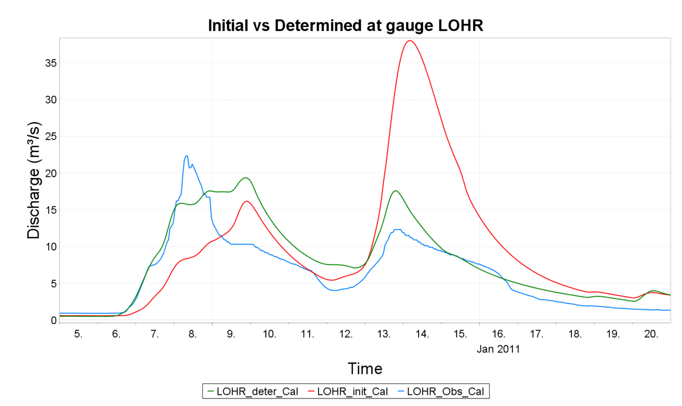

Figure 11: Flow simulation at gauge Lohr

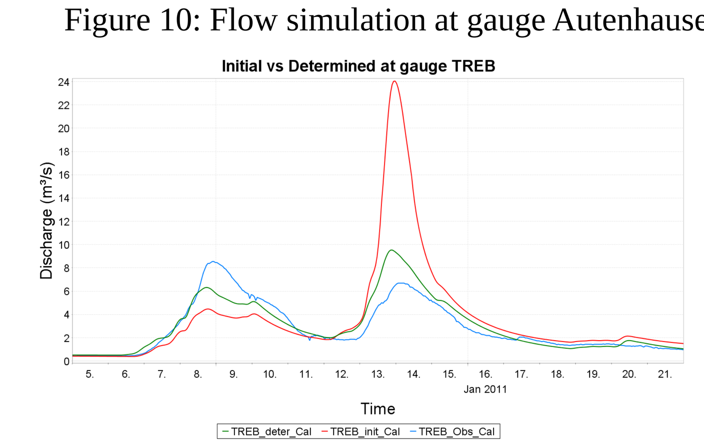

Figure 12: Flow simulation at gauge Trebgast

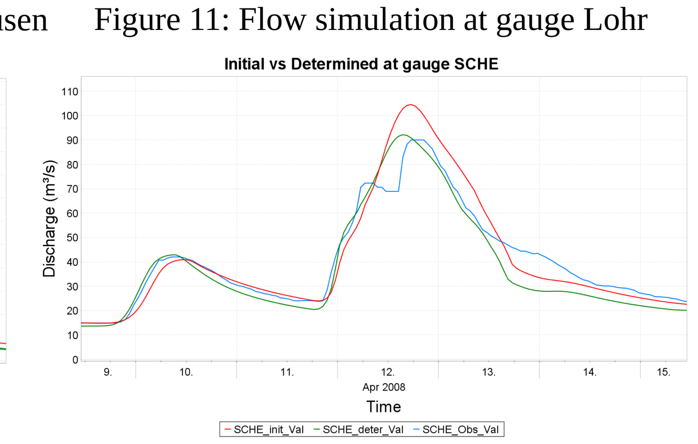

Figure 13: Flow simulation at gauge Schenkenau

- **Effects of questionable observation and precipitation data on the calibration**
  The questionable quality of the observed discharge data has disturbed the calibration process and increased model uncertainty by forcing the calibrated parameters to fit the unrealistic flow. (Figure 14)

  Certain simulations are inert to the increase of observed discharge even after calibration. Hence, the precipitation data should be examined in order to provide LARSIM model a water balance condition closer to the reality. (Figure 15)

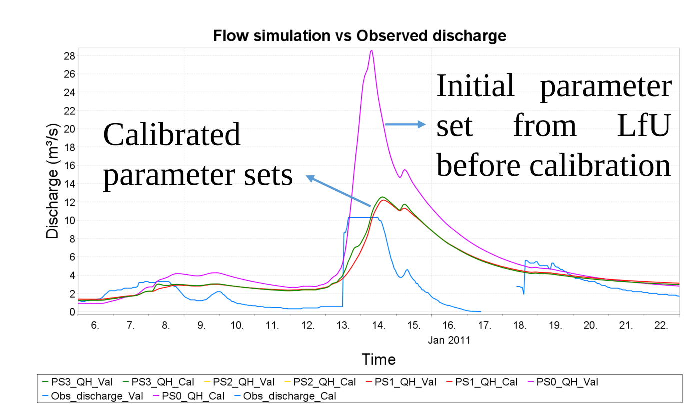

Figure 14: Flow simulation at gauge Wirsberg

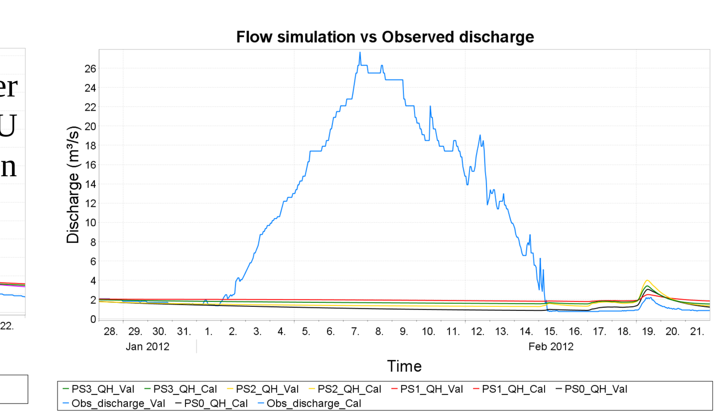

Figure 15: Flow simulation at gauge Bad Berneck (Weißer Main)

9. Conclusion

- The global optimum parameter set does not necessarily provide the most reliable result. Hence, model calibration should not only base on the result from the automatic calibration algorithm.
- Multiple examinations should be taken to address the issue of parameter equifinality for specific applications, and to determine the most representative parameter set.
- The purposed semi-automatic calibration method not only examines the performance of considered parameter sets quantitively, but also visually by comparing the plausibility of hydrograph components. Reliable simulations are returned in an efficient way, and are creditable in the application of flood forecast in the Upper Main catchment.
- Detailed examination on the observed discharge and precipitation data within certain time frames are recommended as future work, in order to ensure a more reliable calibration result and a water balance condition which corresponds to the reality.

References

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[2] Ludwig, K., & Bremicker, M. (2006). The Water Balance Model LARSIM - Design, Content and Applications. Freiburg: Institut für Hydrologie der Universität Freiburg i. Br.

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